Plumbing the depths of time

- Curtis Woodcock (Zhe Zhu, Chris Holden, Valerie Pasquarella, Eric Bullock, Pontus Olofsson ….)

Community Goals?

- Reconstruct the history of the surface of Earth
  - Provide maps of surface characteristics at any time (where maps change between dates correspond to locations of land cover change!!)
- Monitor change as it is occurring
  - "management relevant"

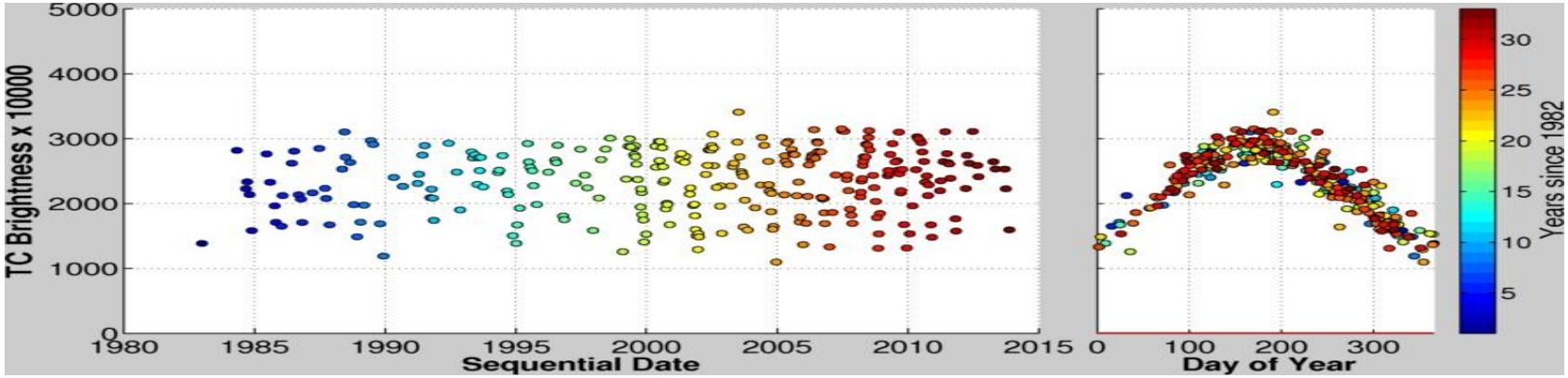
In interesting ways, these are part of the same process!

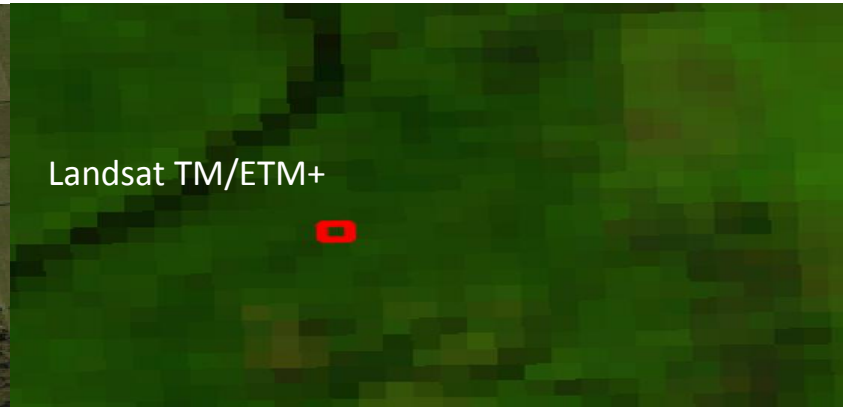
Why ForestSat is sooo relevant now!

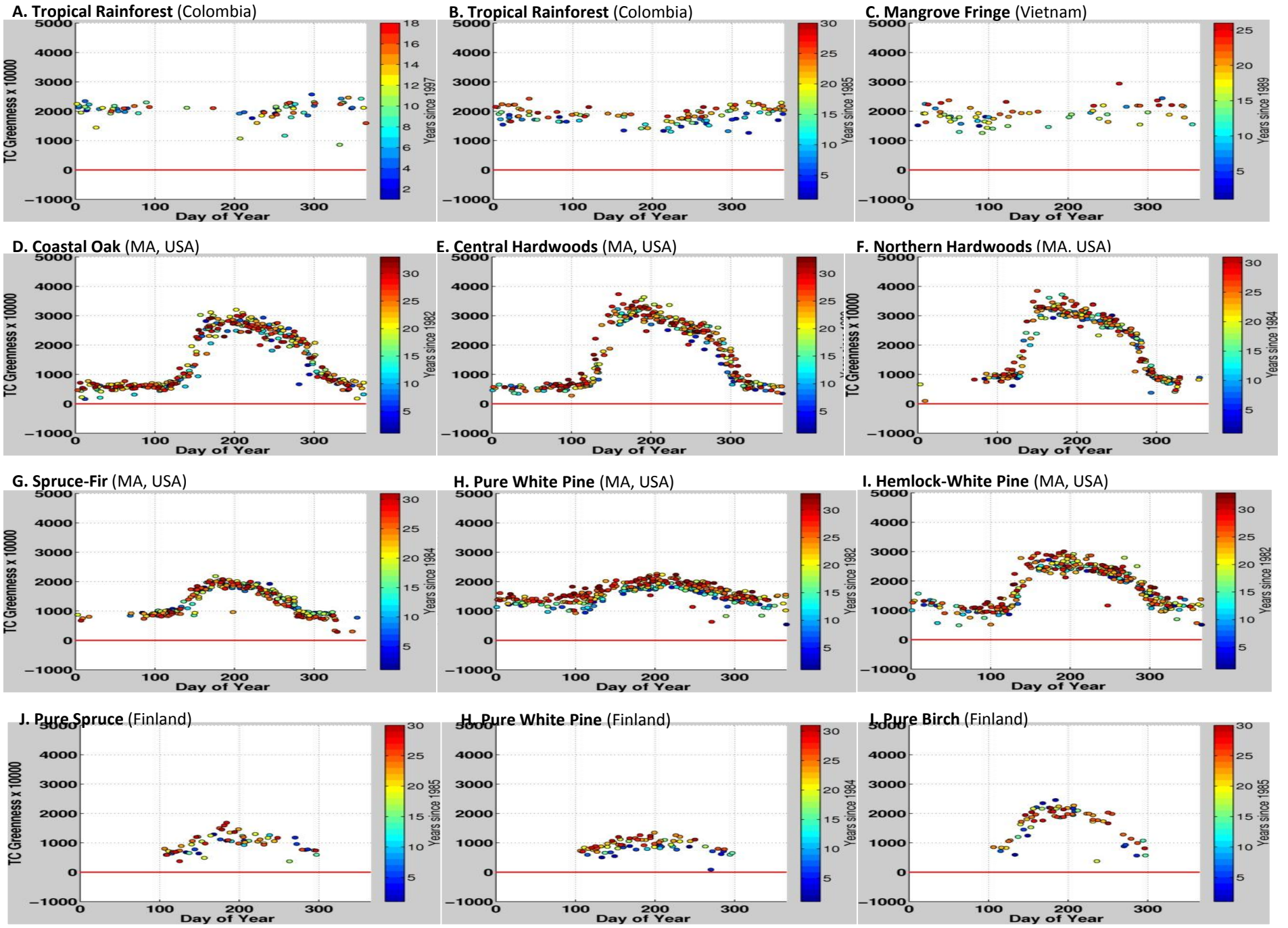
- After 40+ years, we are still learning what we can do with Landsat data – fair to say we are learning more about cool things to do with Landsat at a faster rate than anytime in the past!
- Consistent data formats
- Computing capabilities
- Archive consolidation (LGAC)
- Calibration/automated atmospheric correction
- Automated Cloud and Cloud Shadow Detection
- Free Access – data policy, NASA + USGS
  - Prior to 2008, less than 10% of the images in the archive had ever been used! Now it is over 80% and only the completely cloud covered images have never been used

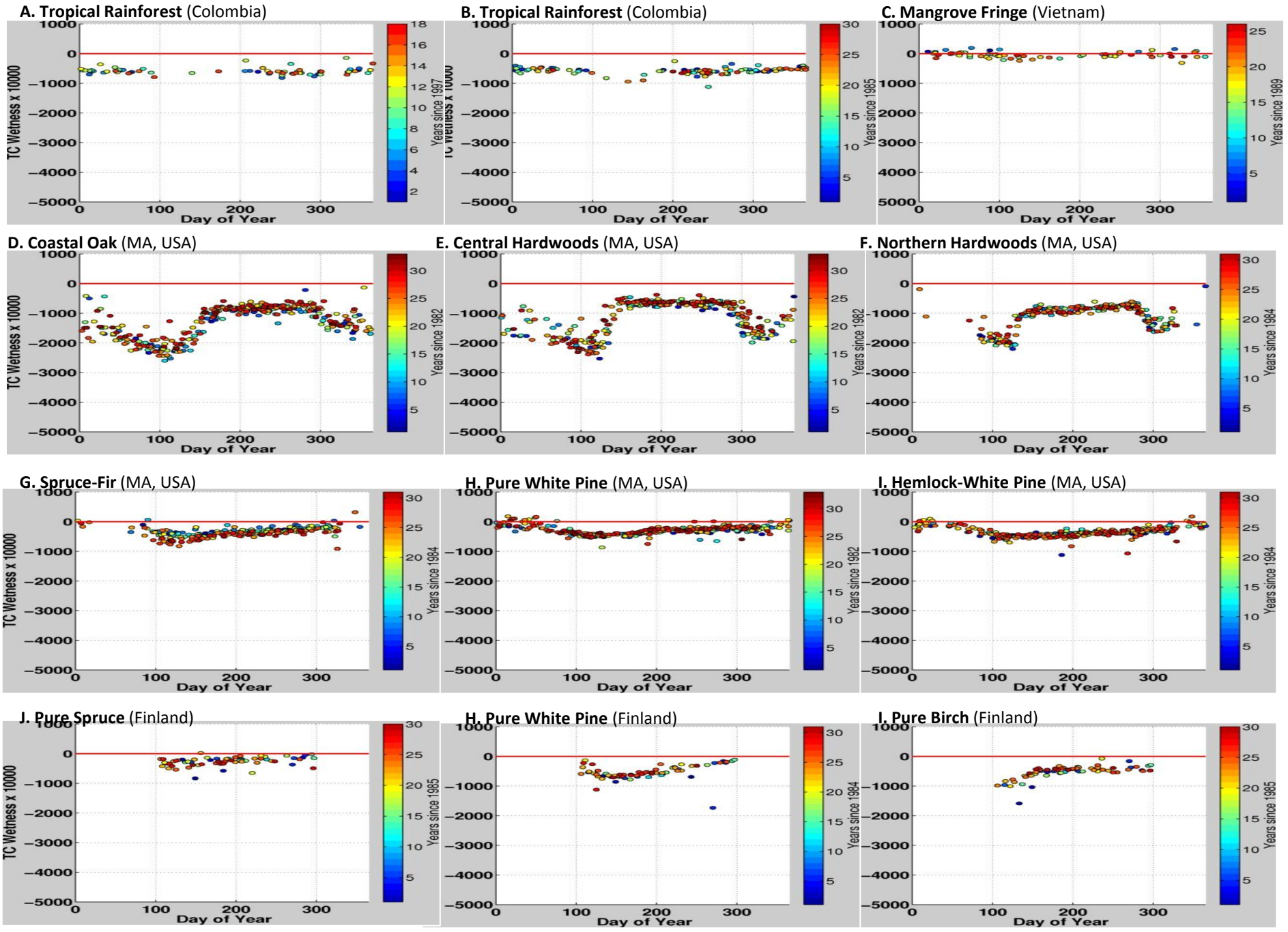
- New kinds of information from Landsat
  - Detection of more subtle disturbance
  - More reliable disturbance detection
  - Trends in ecosystem health and growth
  - Forest phenology – both average and interannual
  - Peak greenness – as indications of trends in ecosystem health and climate response
  - Improved ability to map forest composition

Here are two way we are looking at the history of Landsat data for individual pixels: a time series on the left and an “average annual phenology” or “day of year” graph on the right (slides from Valerie Pasquarella)






A. Tropical Rainforest (Colombia)
B. Tropical Rainforest (Colombia)
C. Mangrove Fringe (Vietnam)
D. Coastal Oak (MA, USA)
E. Central Hardwoods (MA, USA)
F. Northern Hardwoods (MA. USA)
G. Spruce-Fir (MA, USA)
H. Pure White Pine (MA, USA)
I. Hemlock-White Pine (MA, USA)
J. Pure Spruce (Finland)
H. Pure White Pine (Finland)
I. Pure Birch (Finland)
TC Greenness x 10000
Day of Year
Years since 1997
Years since 1985
Years since 1989
Years since 1982
Years since 1984
Years since 1982
Years since 1985
Years since 1984
Years since 1985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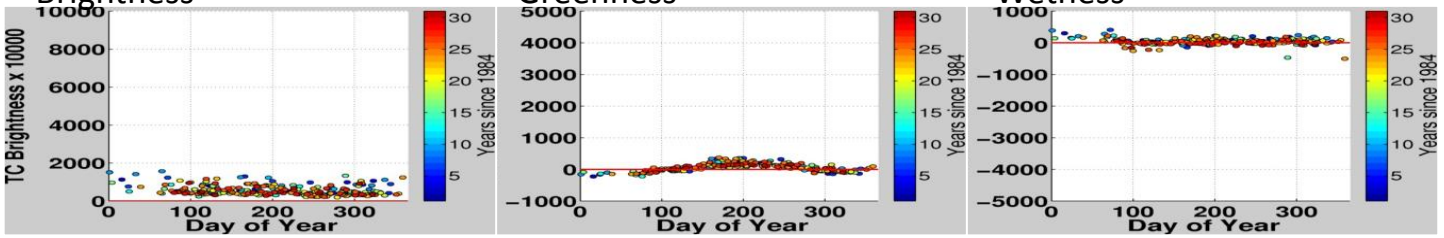
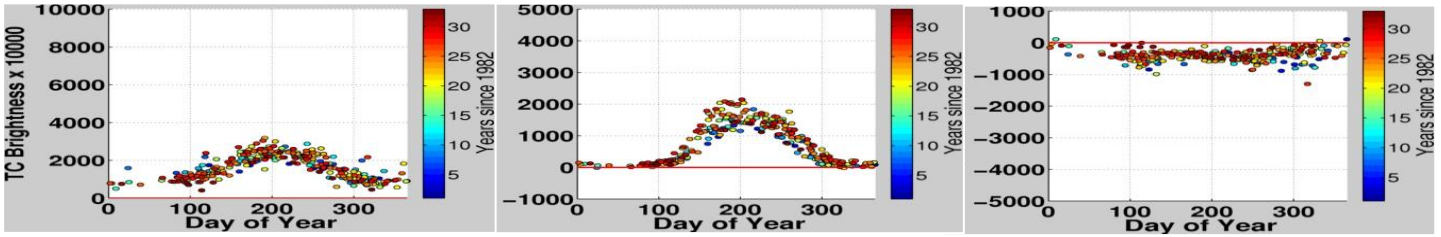
I. Hemlock-White Pine (MA, USA)
J. Pure Spruce (Finland)
H. Pure White Pine (Finland)
I. Pure Birch (Finland)
TC Wetness x 10000
Day of Year
Years since 1997
Years since 1985
Years since 1989
Years since 1982
Years since 1984
Years since 1985

Brightness | Greenness | Wetness

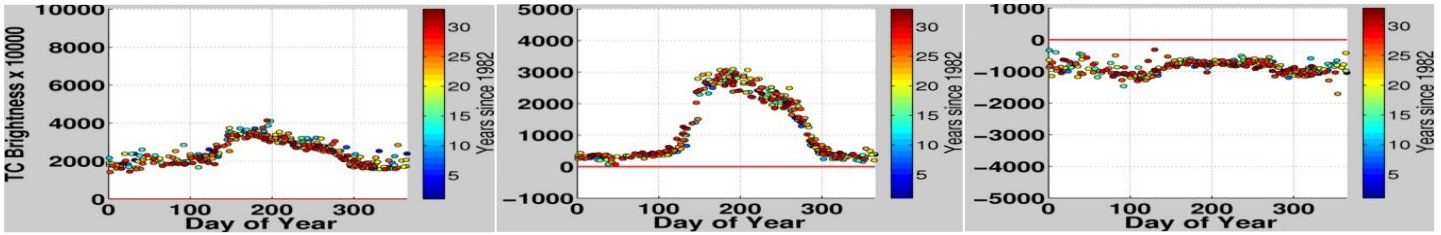
Open Water



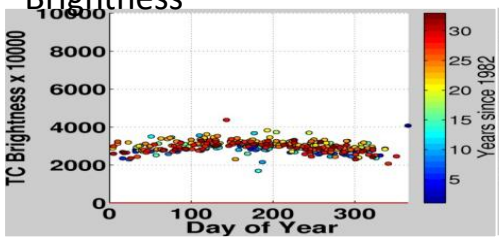
Emergent Wetland

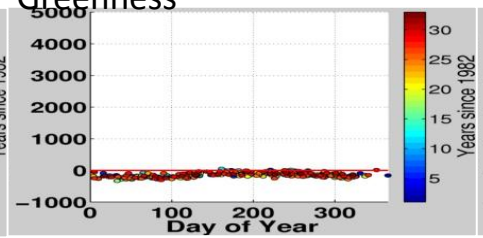


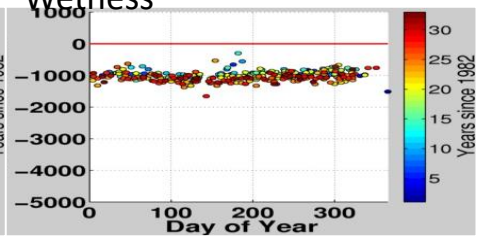
Shrub Swamp

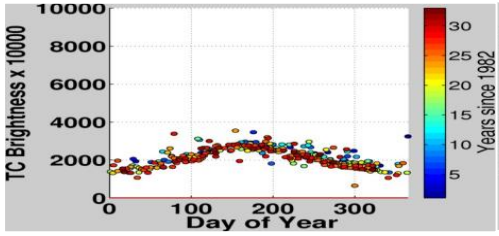


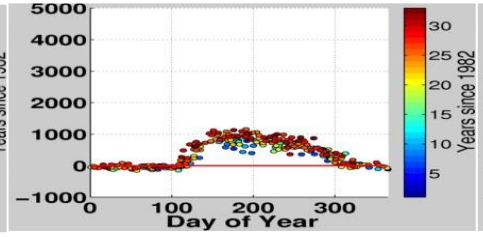
Brightness Greenness Wetness

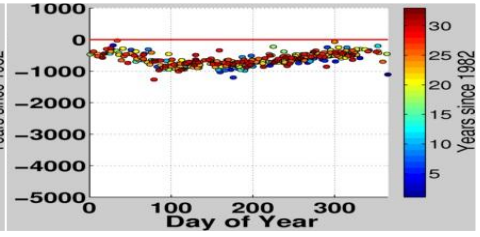


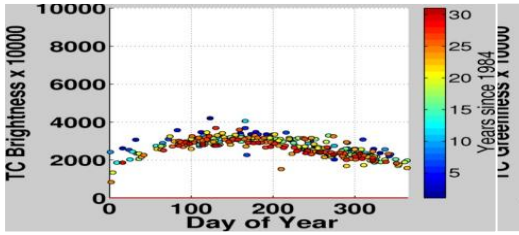


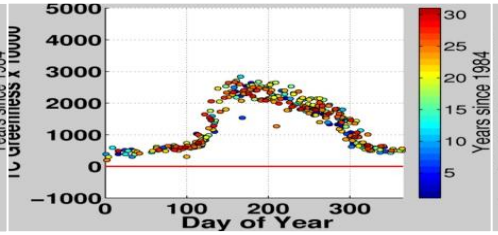


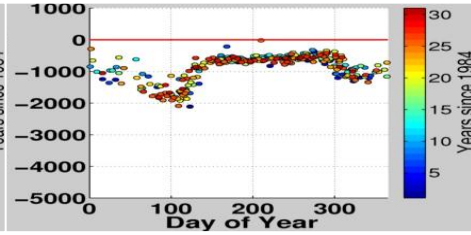


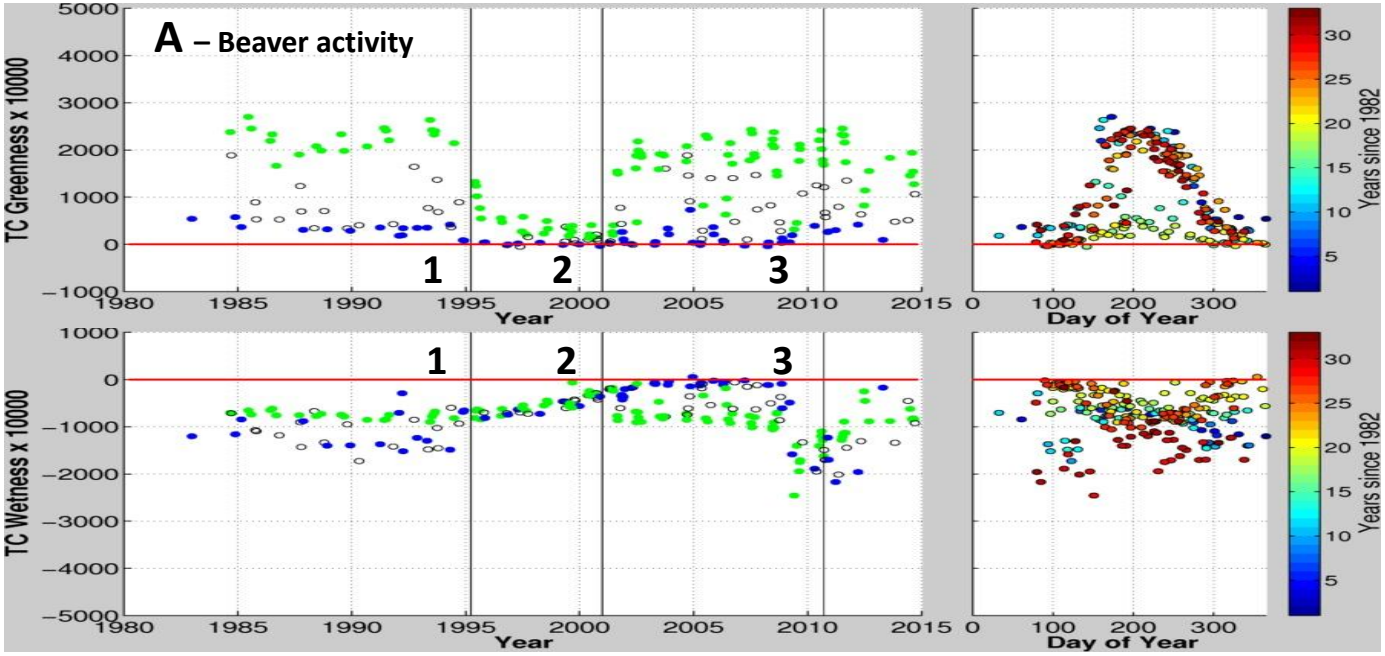


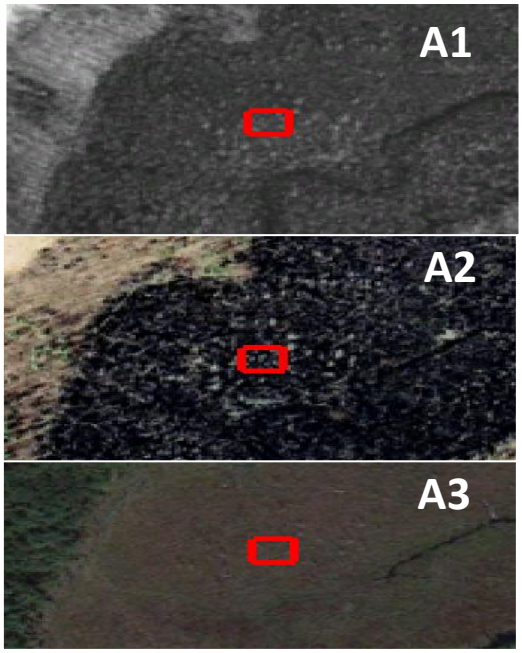


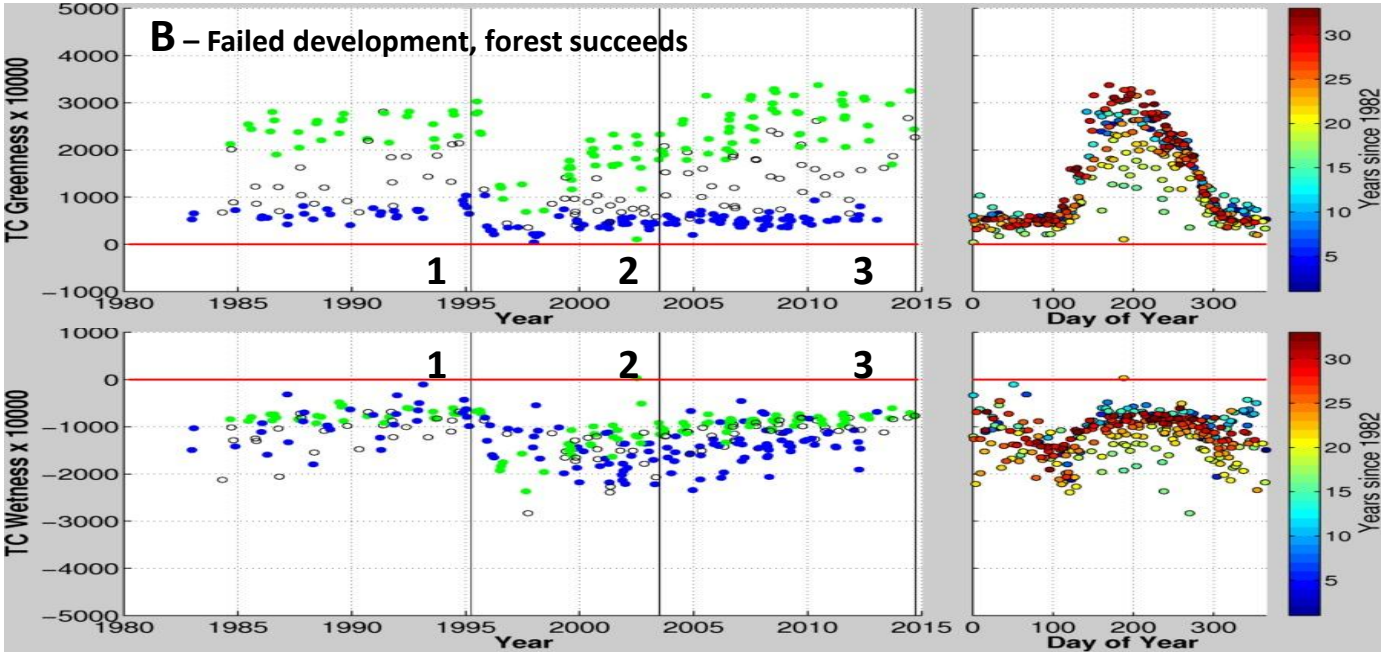


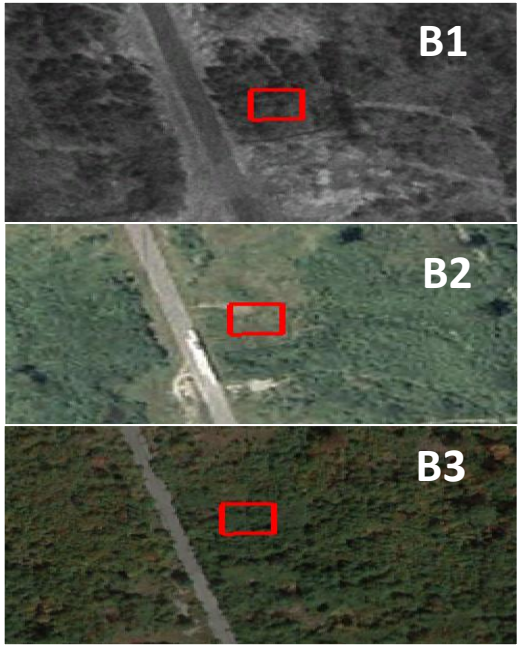


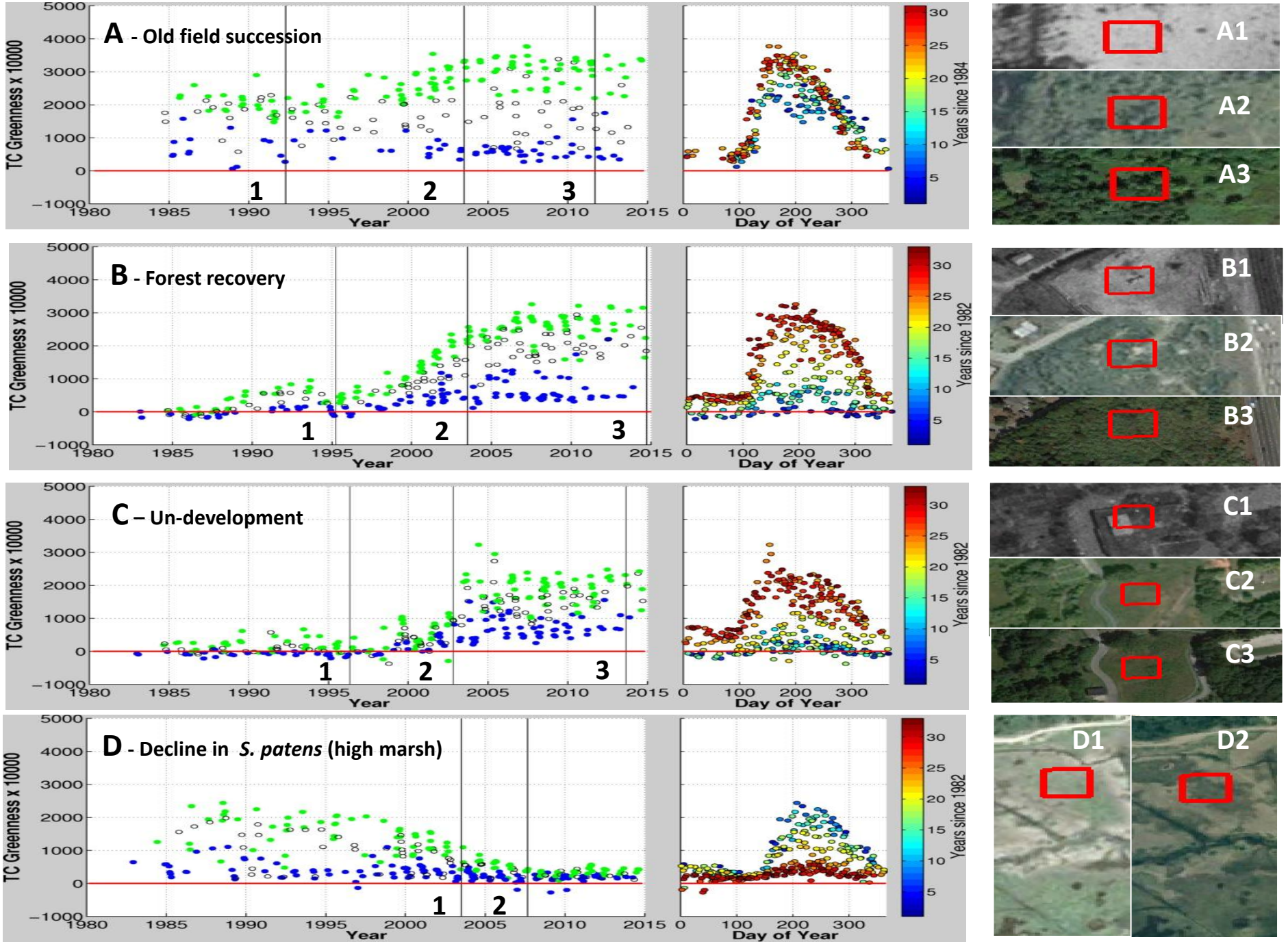



A – Beaver activity
TC Greenness x 10000
TC Wetness x 10000
Year
Day of Year
Years since 1982
1
2
3


A1
A2
A3


B – Failed development, forest succeeds
TC Greenness x 10000
TC Wetness x 10000
Year
Day of Year
Years since 1982
1
2
3

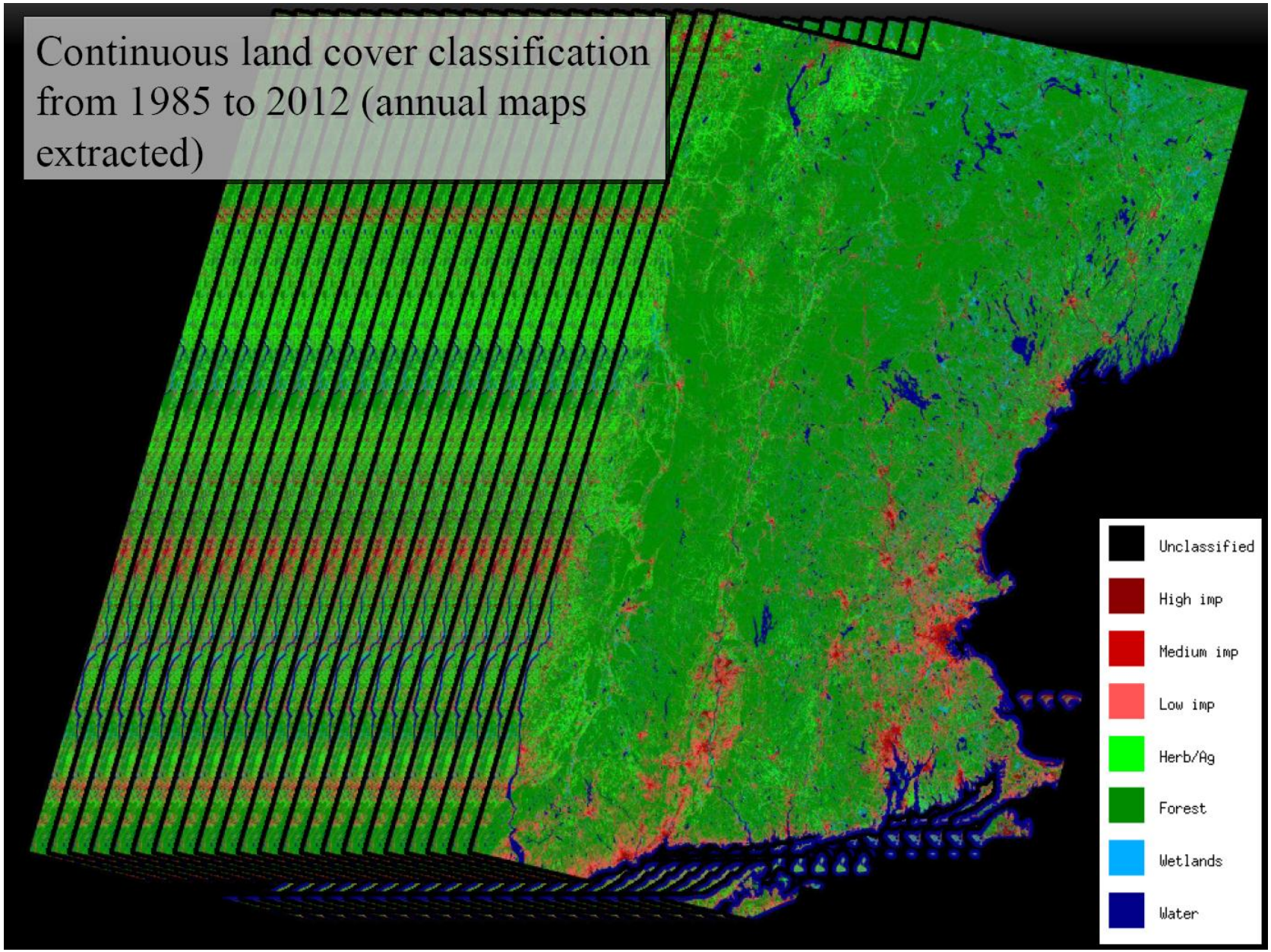

B1
B2
B3


A - Old field succession
B - Forest recovery
C – Un-development
D - Decline in S. patens (high marsh)
TC Greenness x 10000
Year
Day of Year
Years since 1984
Years since 1982
1
2
3
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2

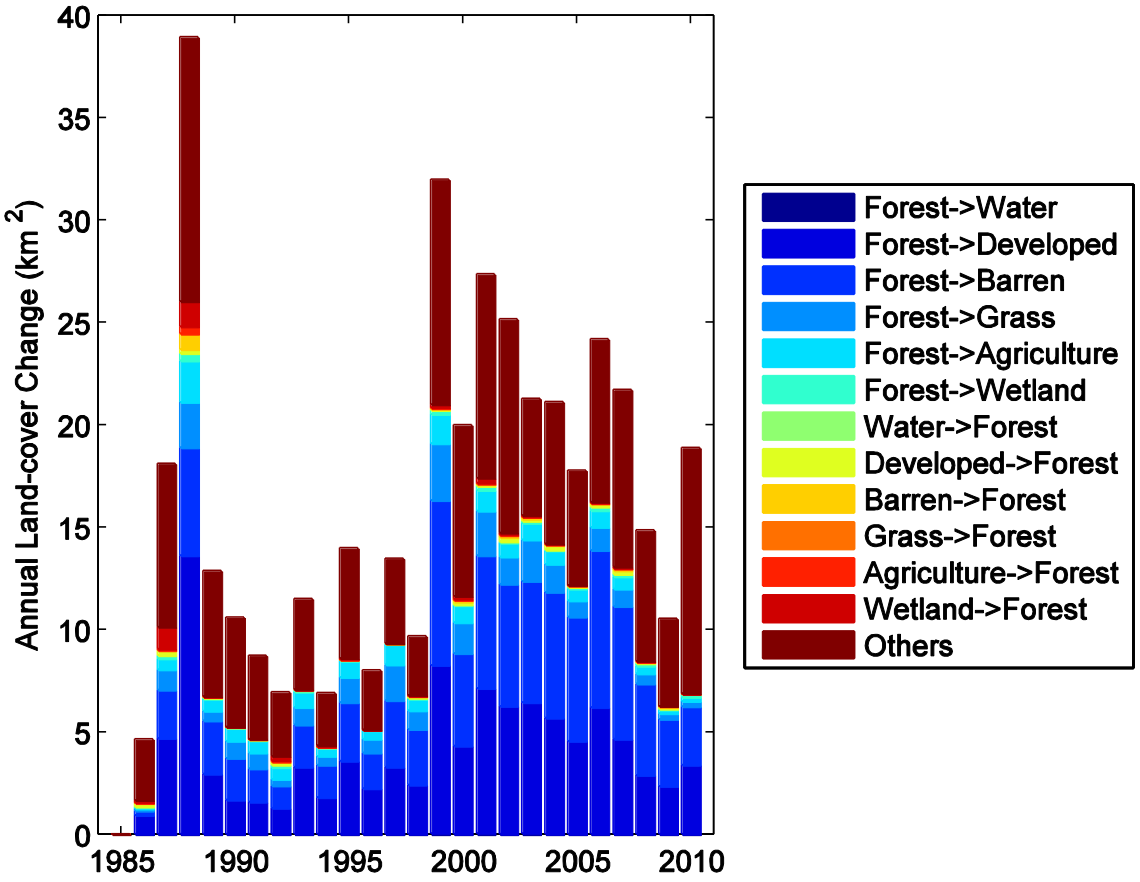
Continuous Change Detection and Classification (Zhu and Woodcock, RSE 2014)

- Use all available Landsat Data, removing clouds, cloud shadows, and snowy observations
- Treat each pixel as a time series
- Fit empirical models (usually based on sinusoids) and compare new observations with those predicted by the existing time series model to find change
- Treat image data as noisy and require seeing change multiple consecutive times before mapping
- Result is maps for any time period that can be compared between time periods to find change

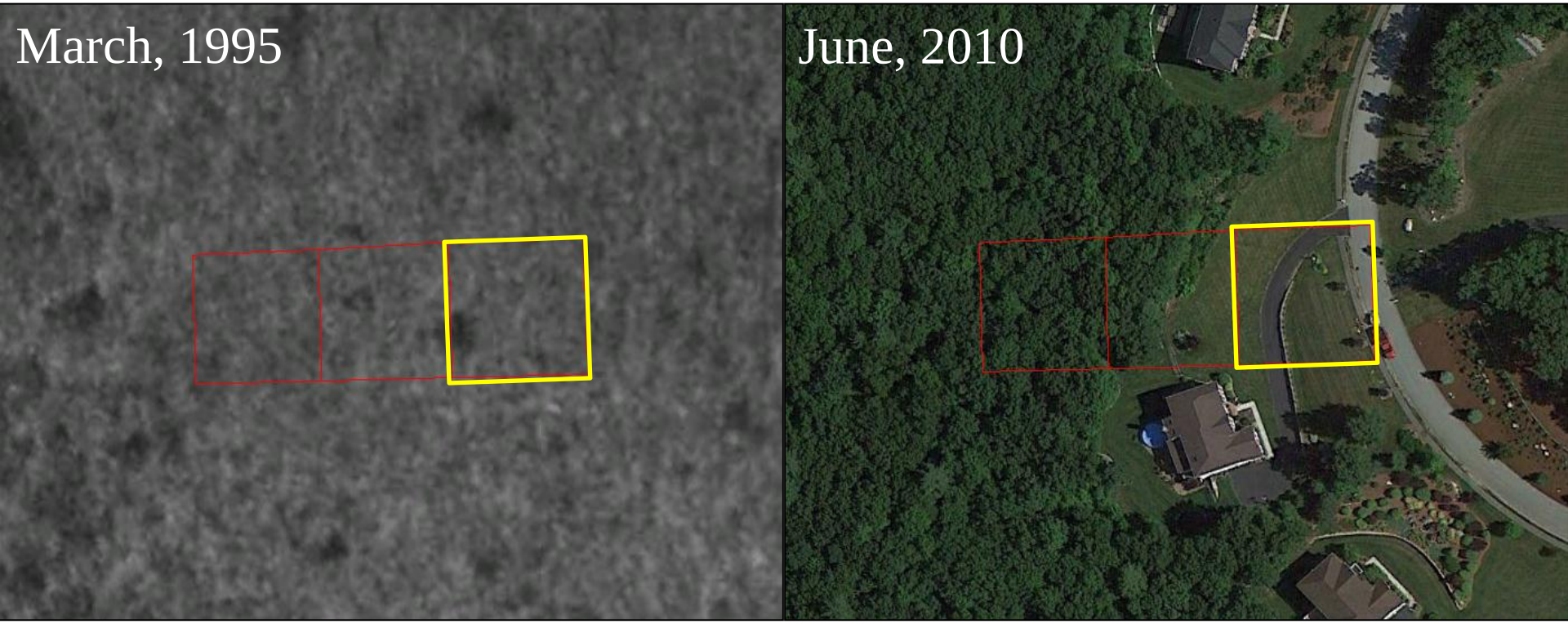
Test in a variety of environments

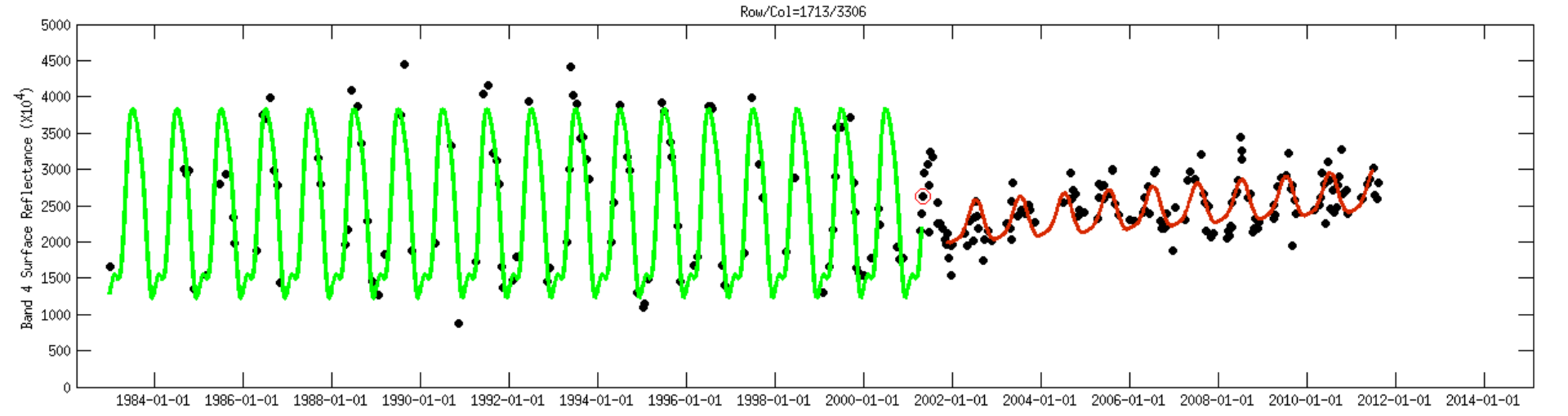


Boston Scene Annual Land Cover Change Histogram

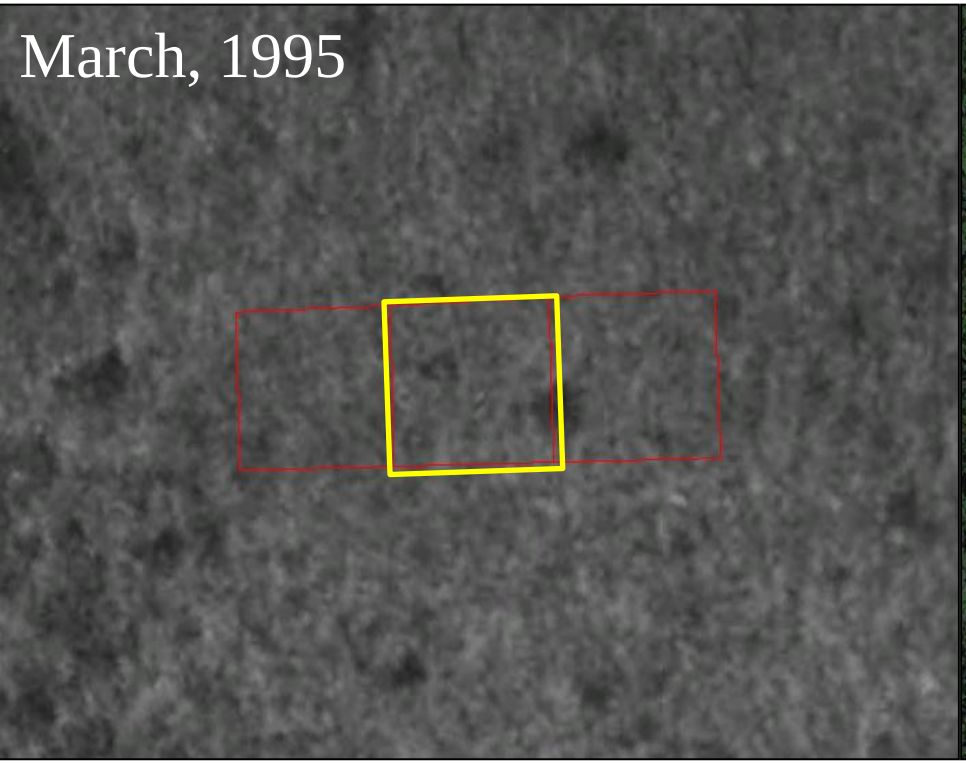


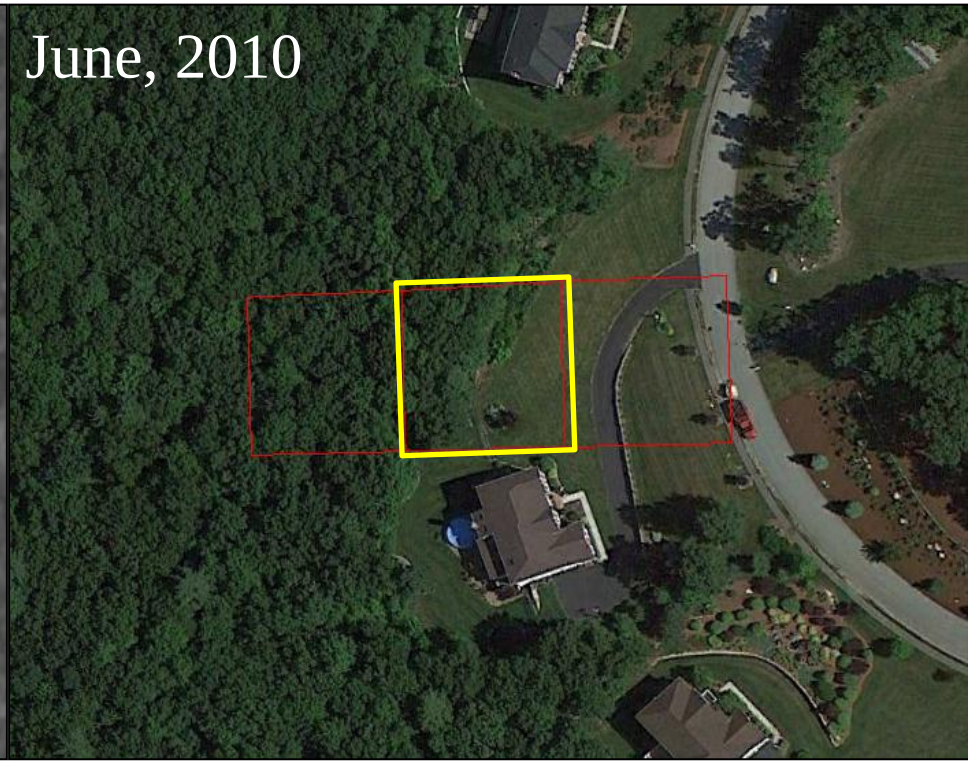
Residential development, Mass. Time-series displayed for pixel represented by yellow square. CCDC classified pixel as ***Dec. Forest*** until April 2001 and then as ***Low Dens. Residential***.

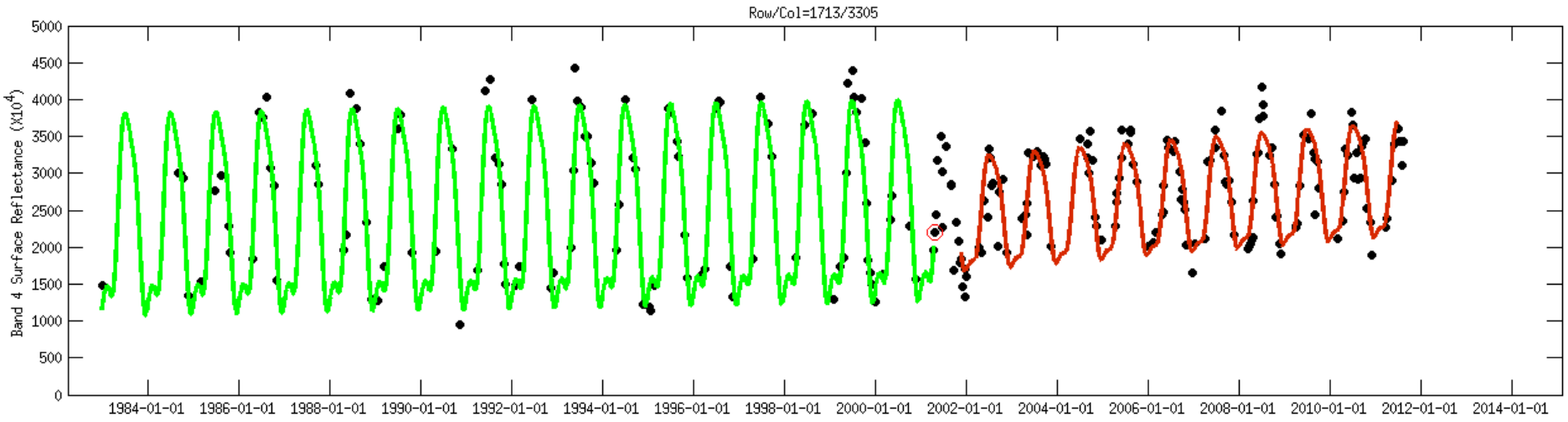




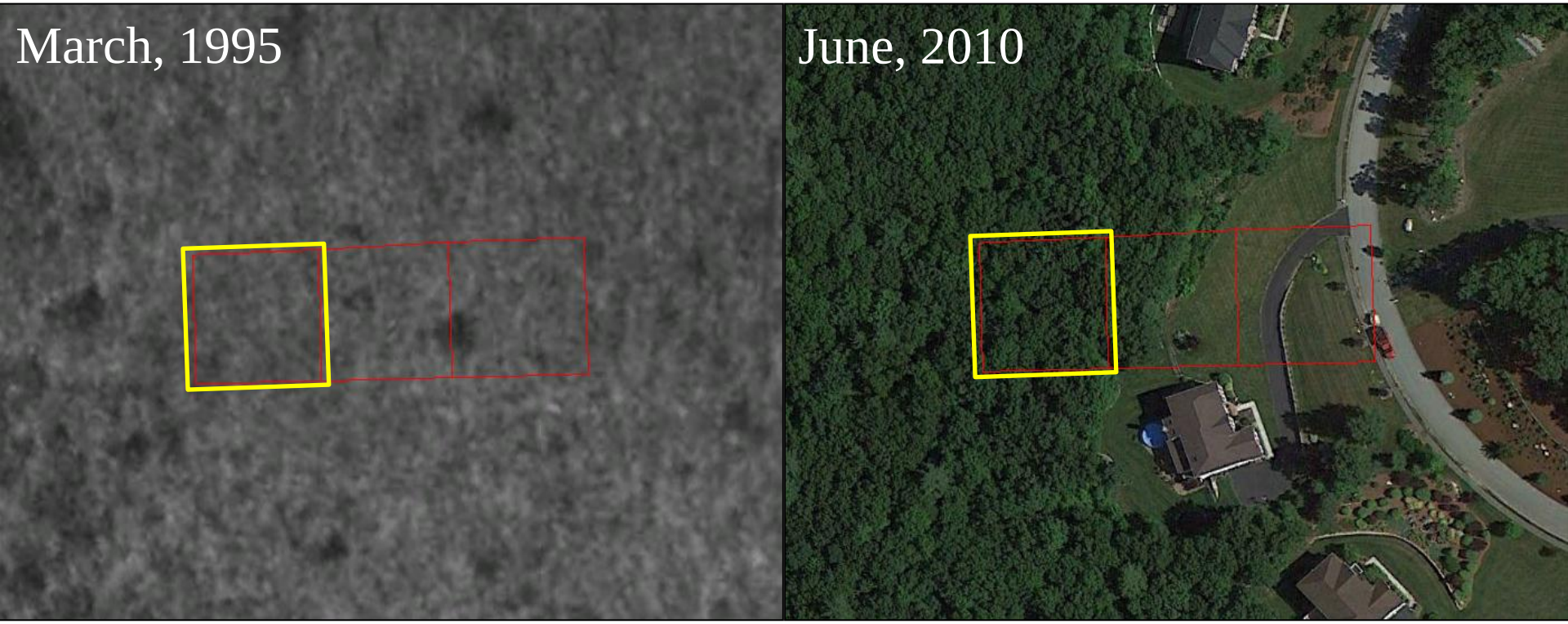
Residential development, Mass. Time-series displayed for pixel represented by yellow square. CCDC classified pixel as ***Dec. Forest*** until May 2001 and then as ***Low Dens. Residential***.

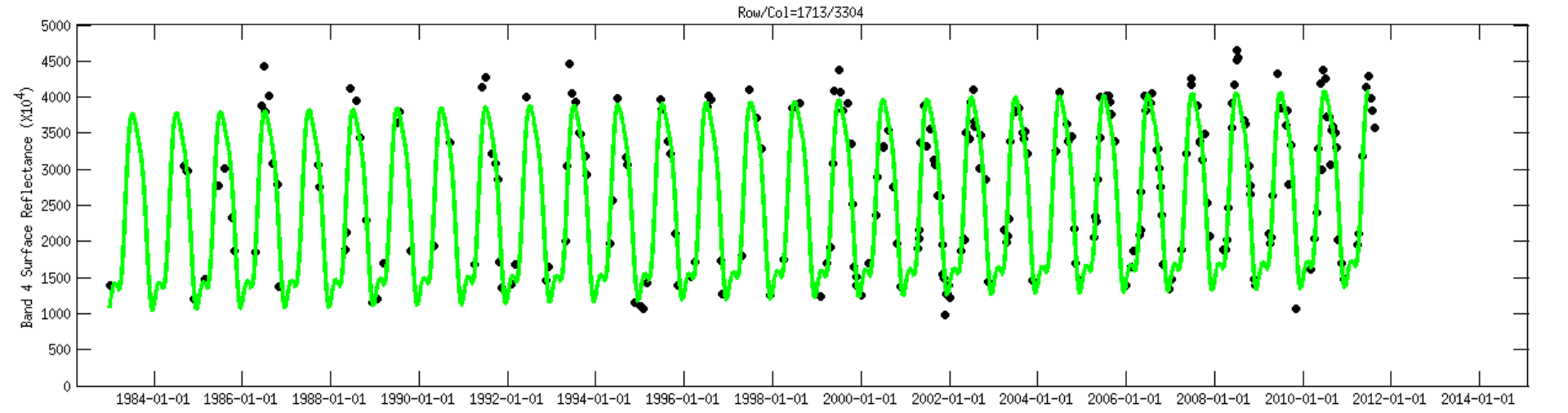




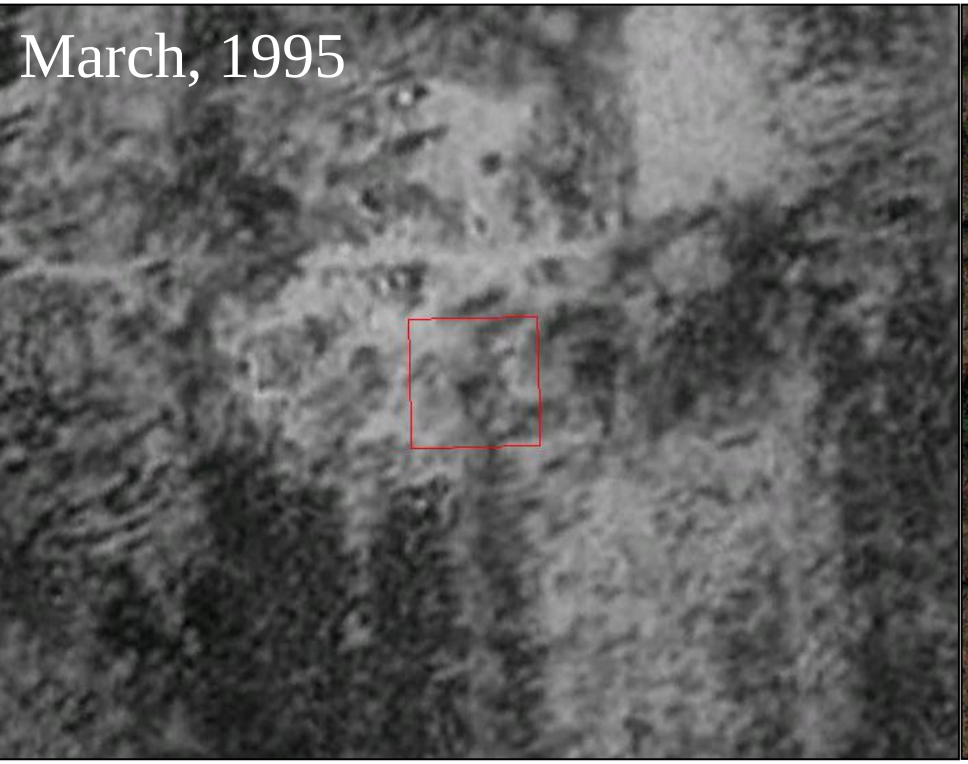


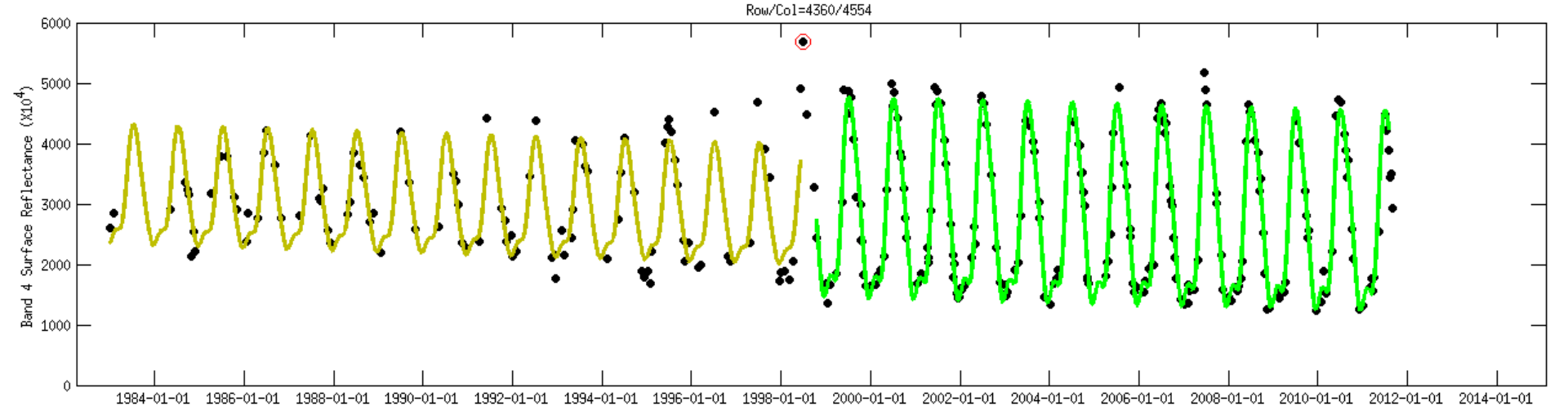
Residential development, Mass. Time-series displayed for pixel represented by the yellow square. CCDC classified pixel as stable ***Dec. Forest***.

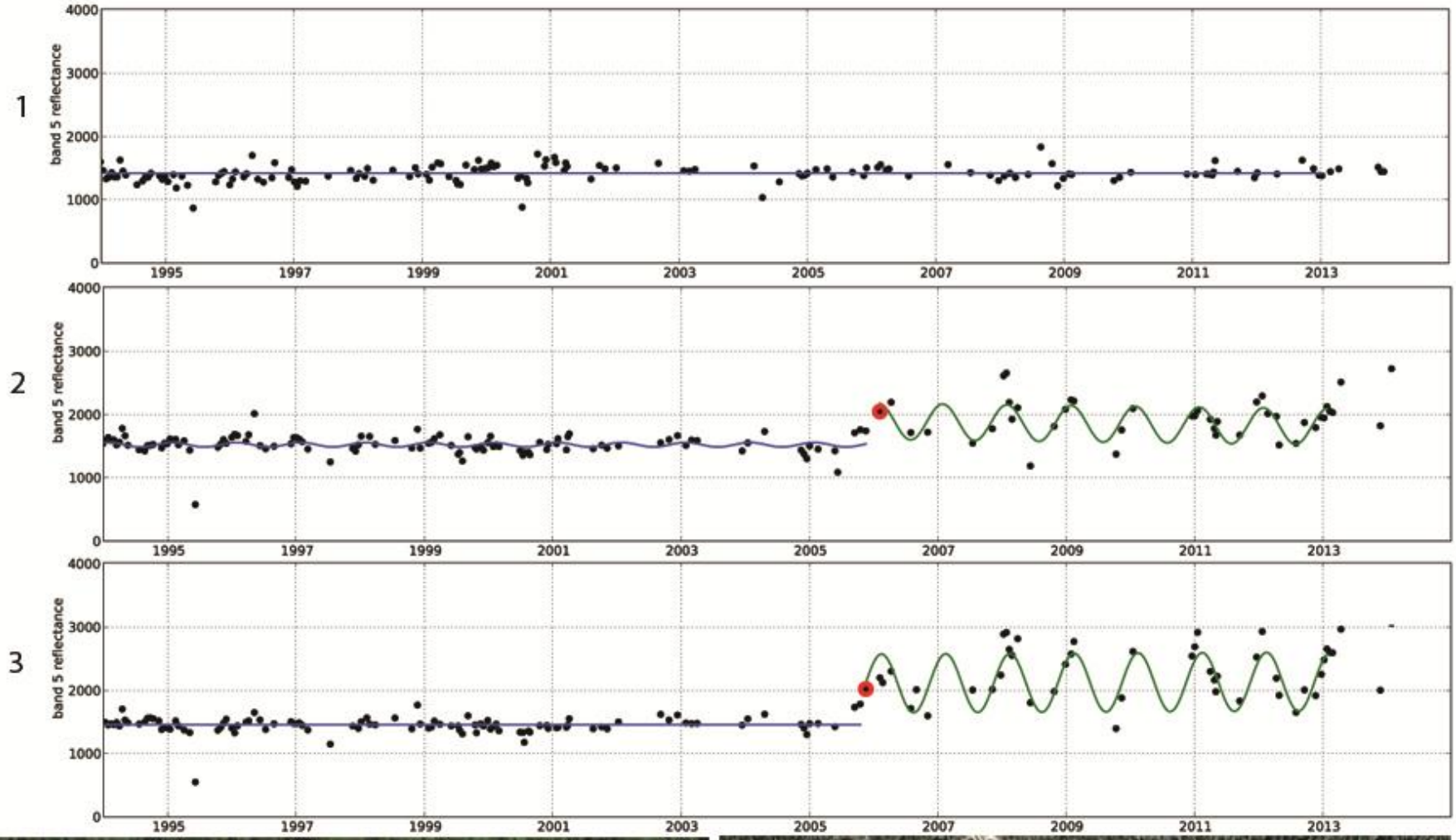




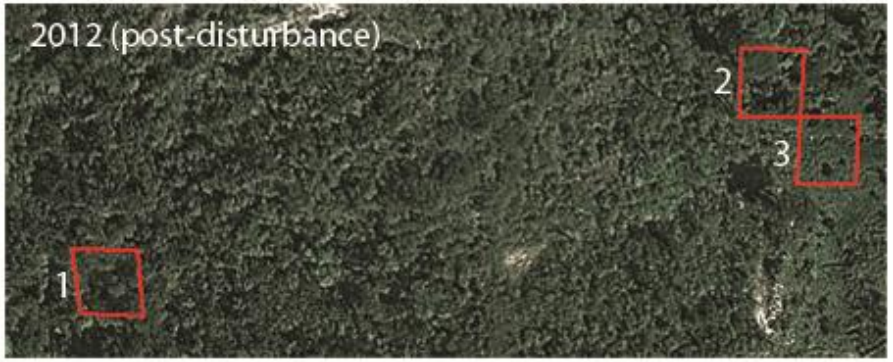
Abandoned farmland near New Bedford, MA. Time-series displayed for the pixel represented by the red square. CCDC classified pixel as ***Pasture/Row Crops*** until Jun 1998 and then as ***Dec. Forest***.



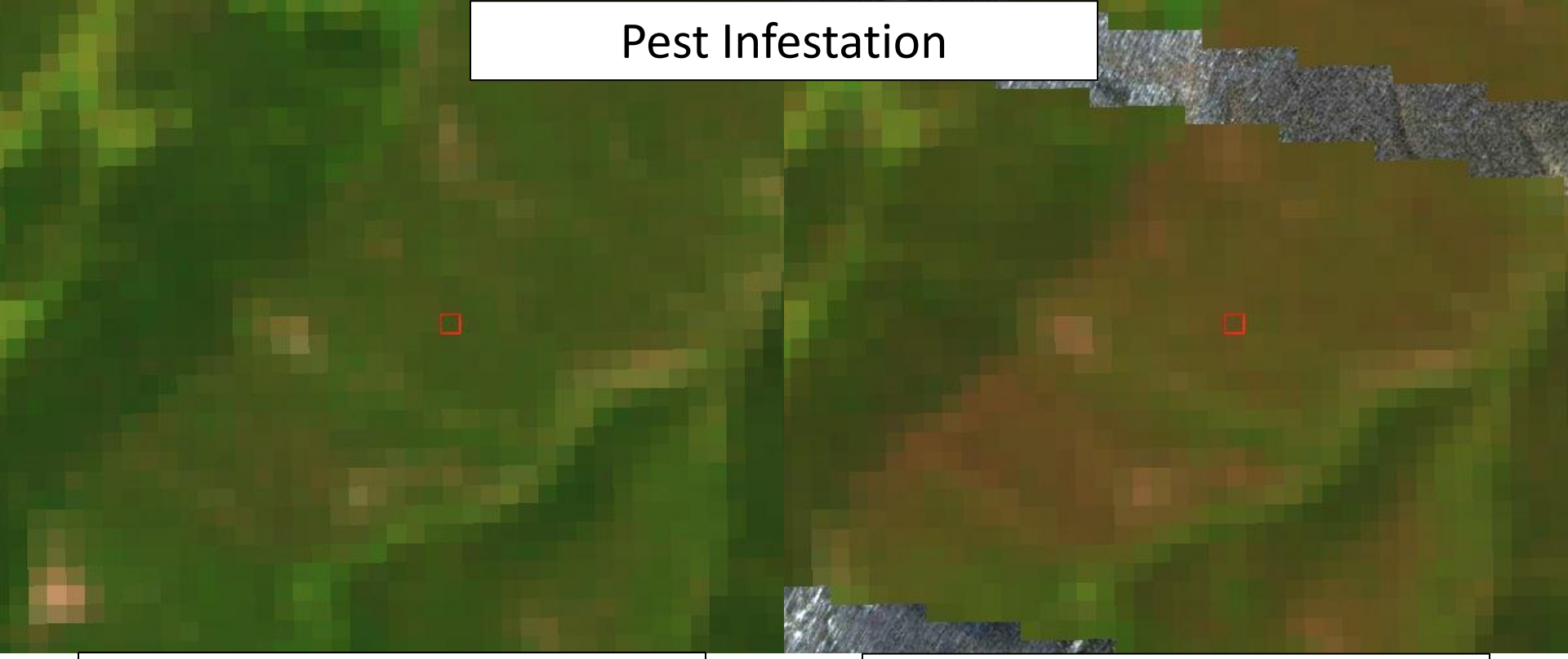



1
2
3
band 5 reflectance
0
1000
2000
3000
4000
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013


2005 (pre-disturbance)
1
2
3

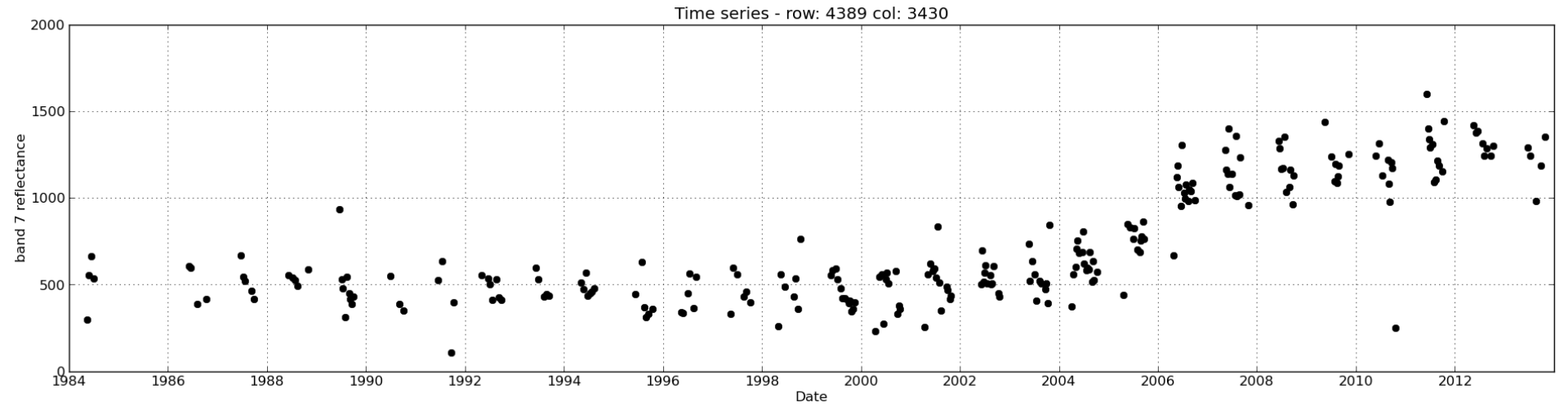

2012 (post-disturbance)
1
2
3

Pest Infestation

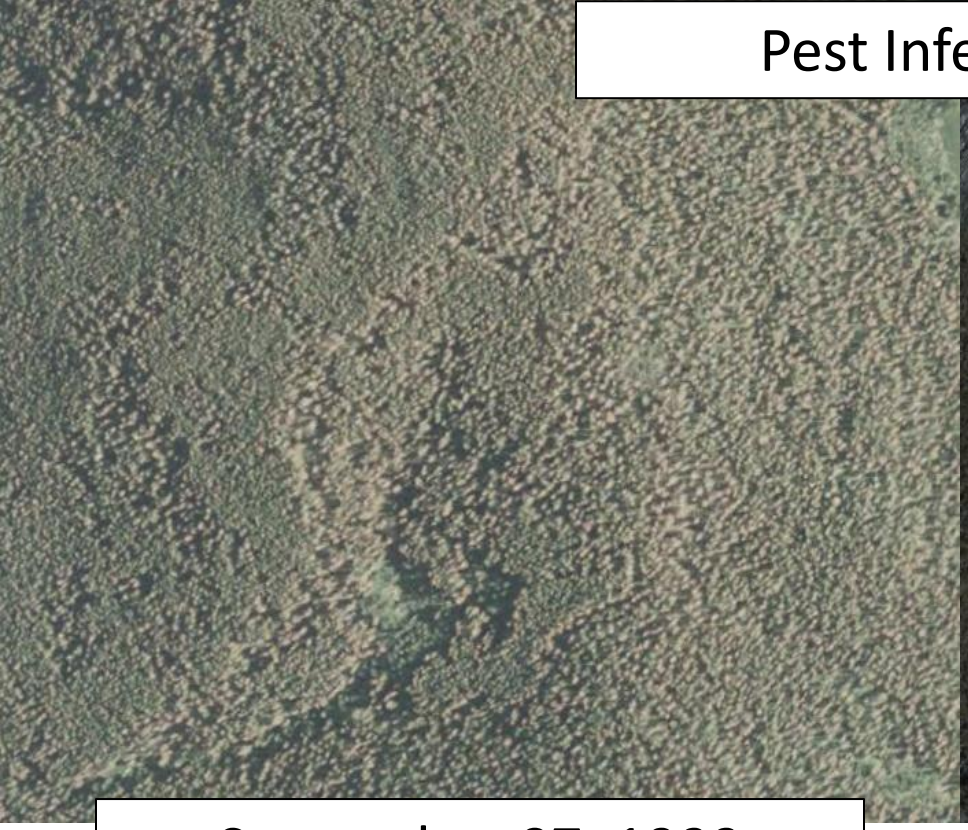


June 2, 1984

June 21, 2013

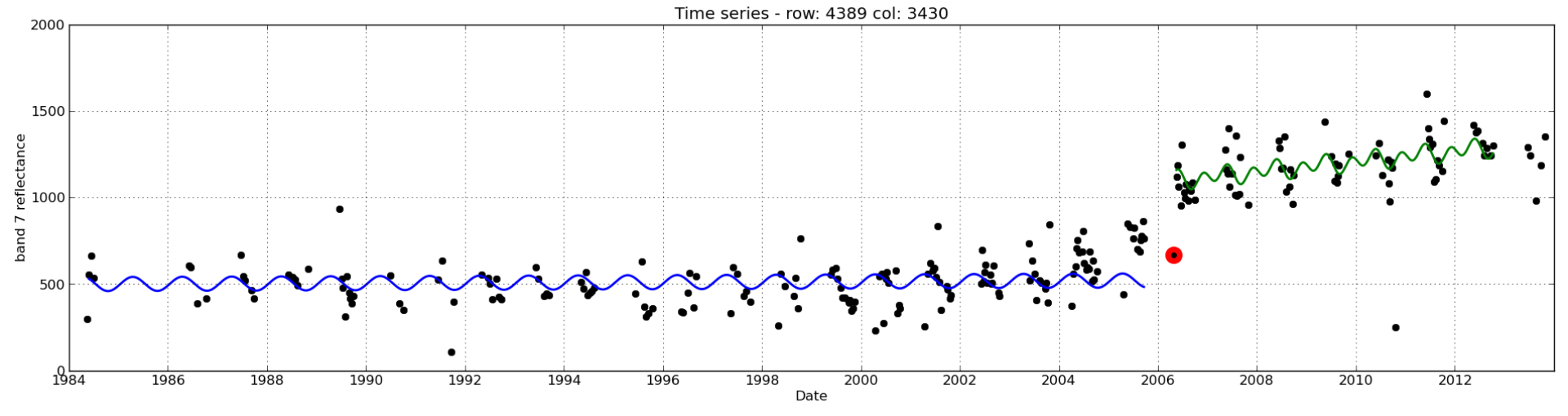


Pest Infestation



September 07, 1999

October 27, 2011



Examples from boreal Canada of fire (top), harvest and fire (middle) and thinning (bottom)

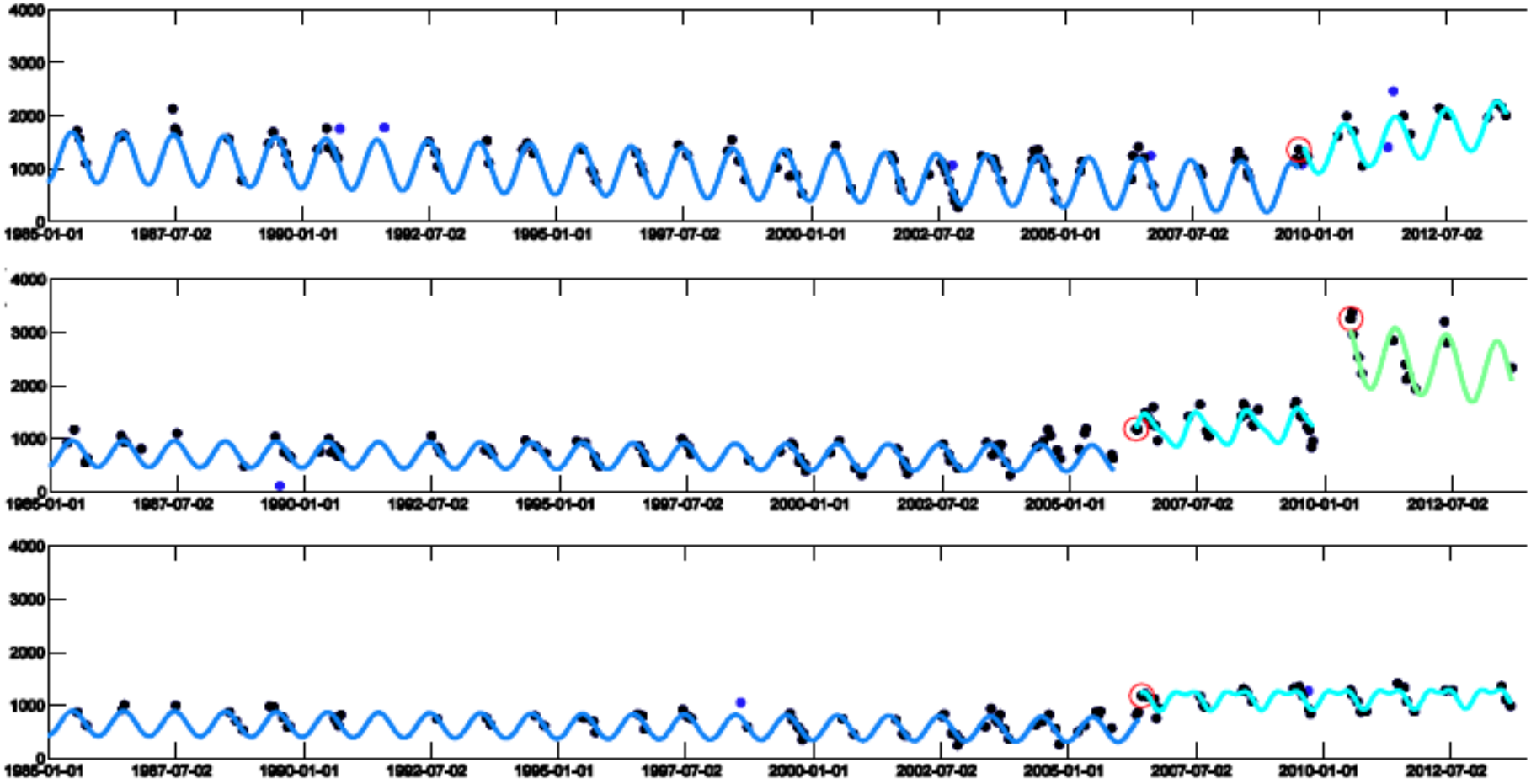
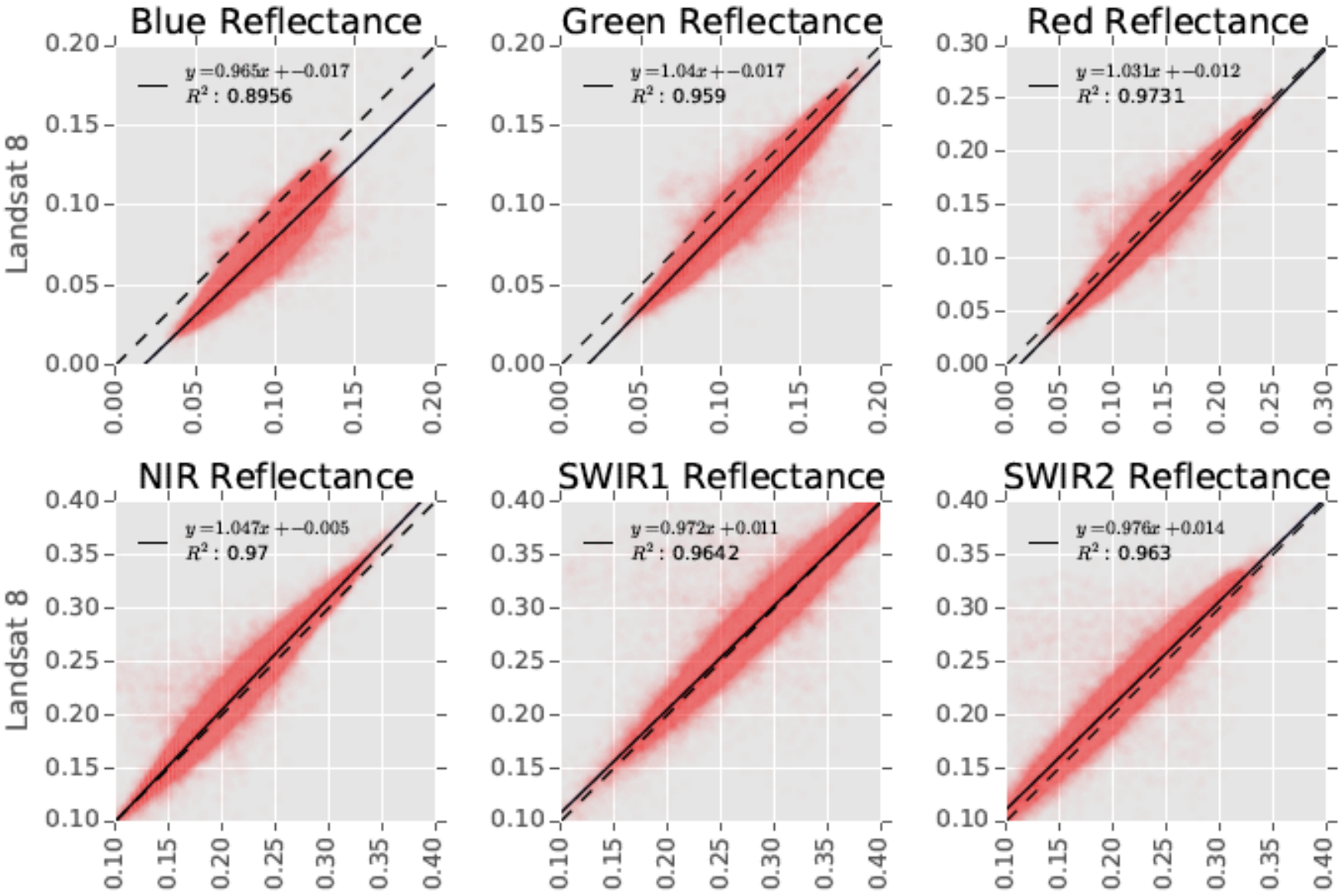


Figure 2. Time series results for 3 pixels with different combinations of disturbance for a location in Central British Columbia. The vertical axis is the Landsat SWIR Band 5 reflectance and is scaled by 10000. The horizontal axis is time and covers three decades. It is interesting to note the negative slope in the initial time series in the top graph, which is indicative of forest growth.

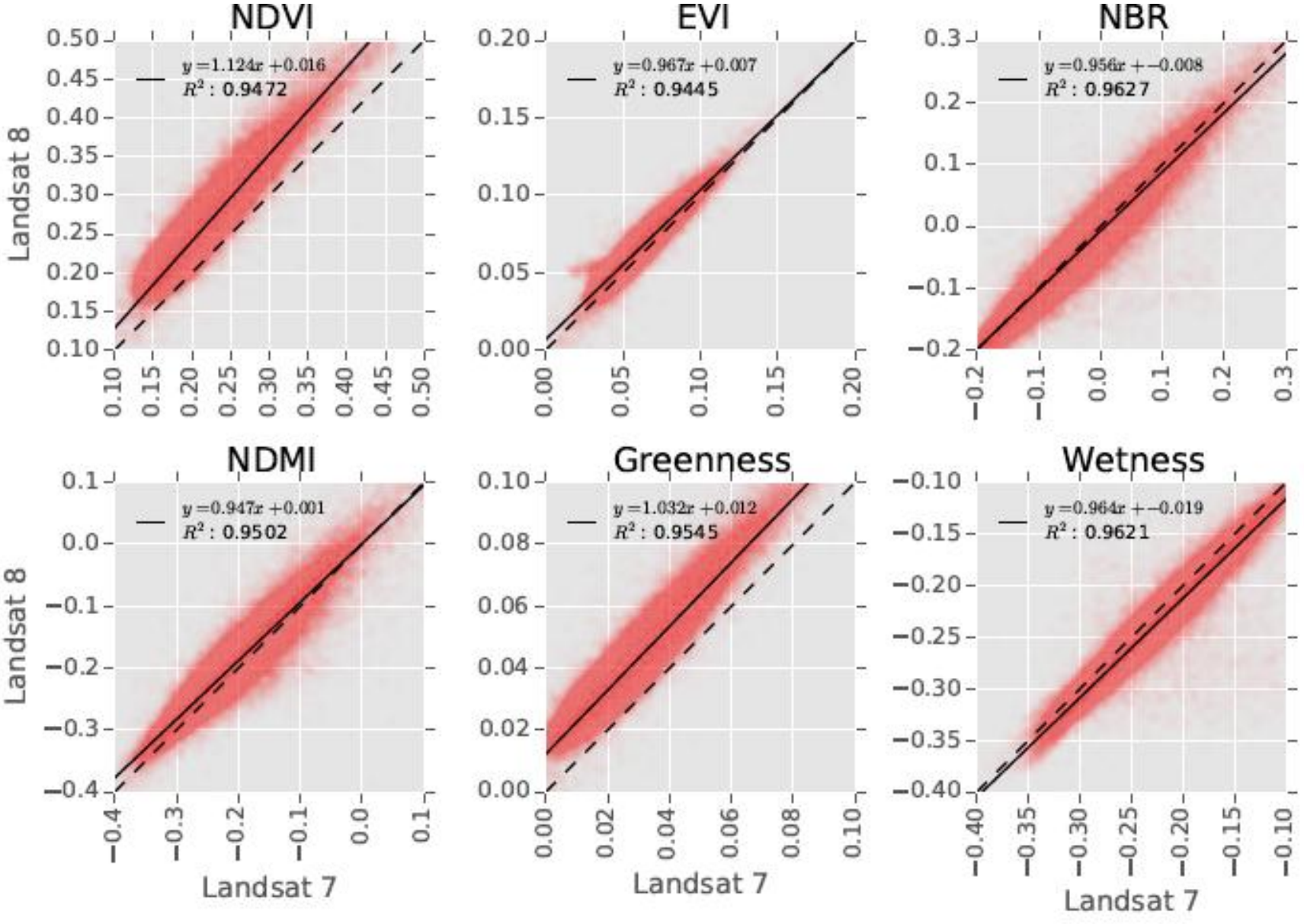
What about time series and L8?

- Spectral differences
- Cirrus clouds

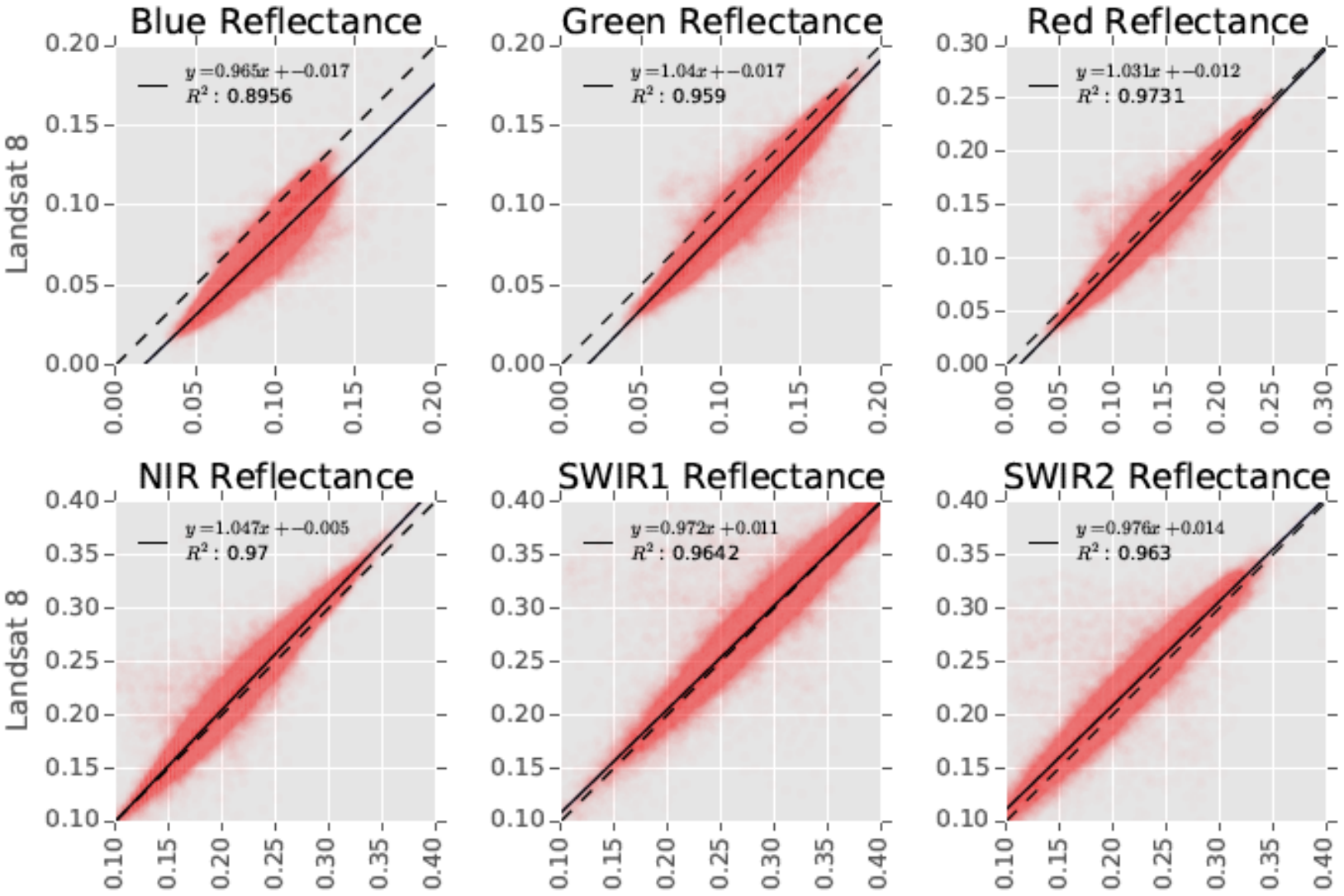
Comparison of L8 and L7 from underflight data



Various indices (underflight)



Comparison of L8 and L7 from underflight data



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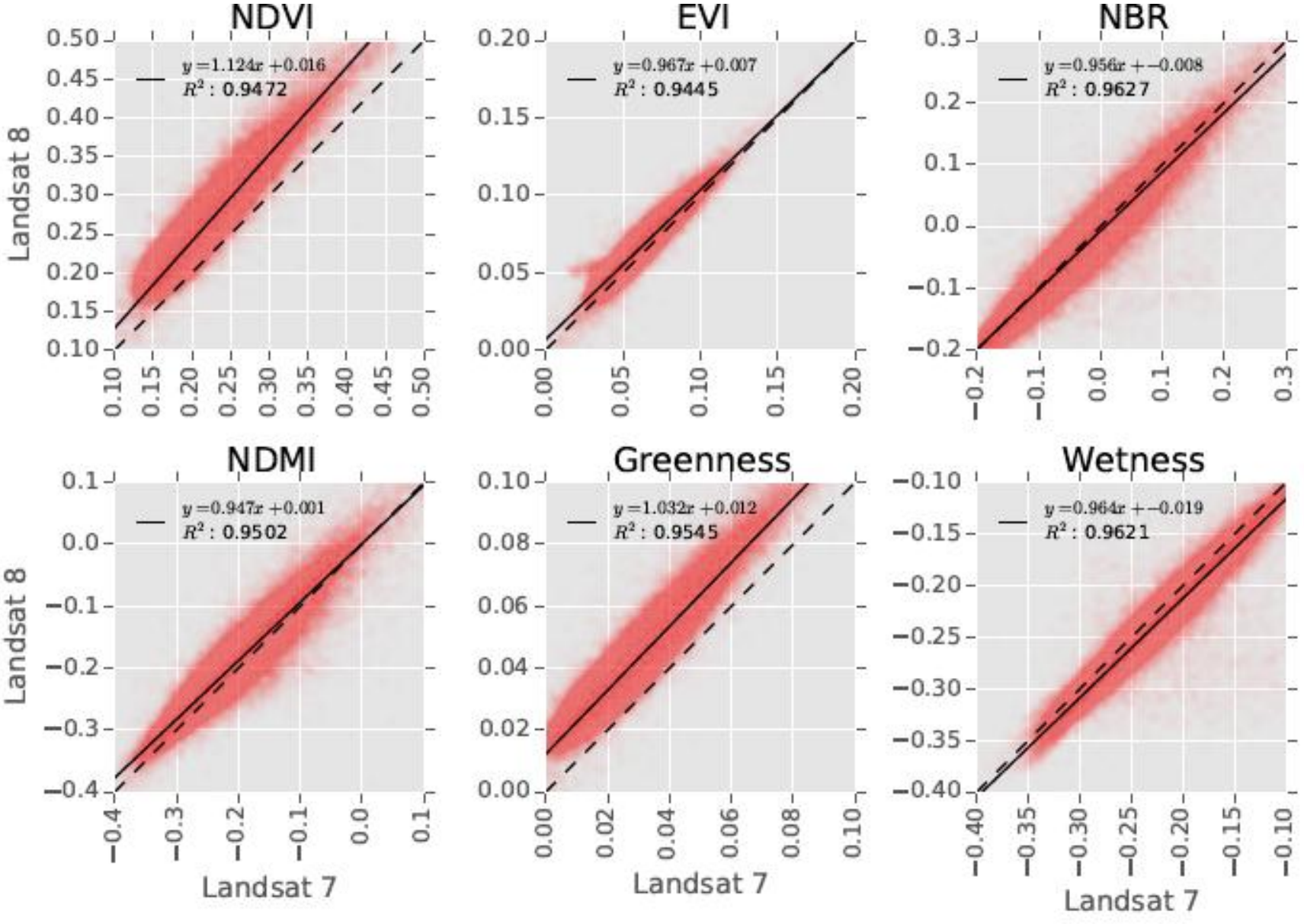
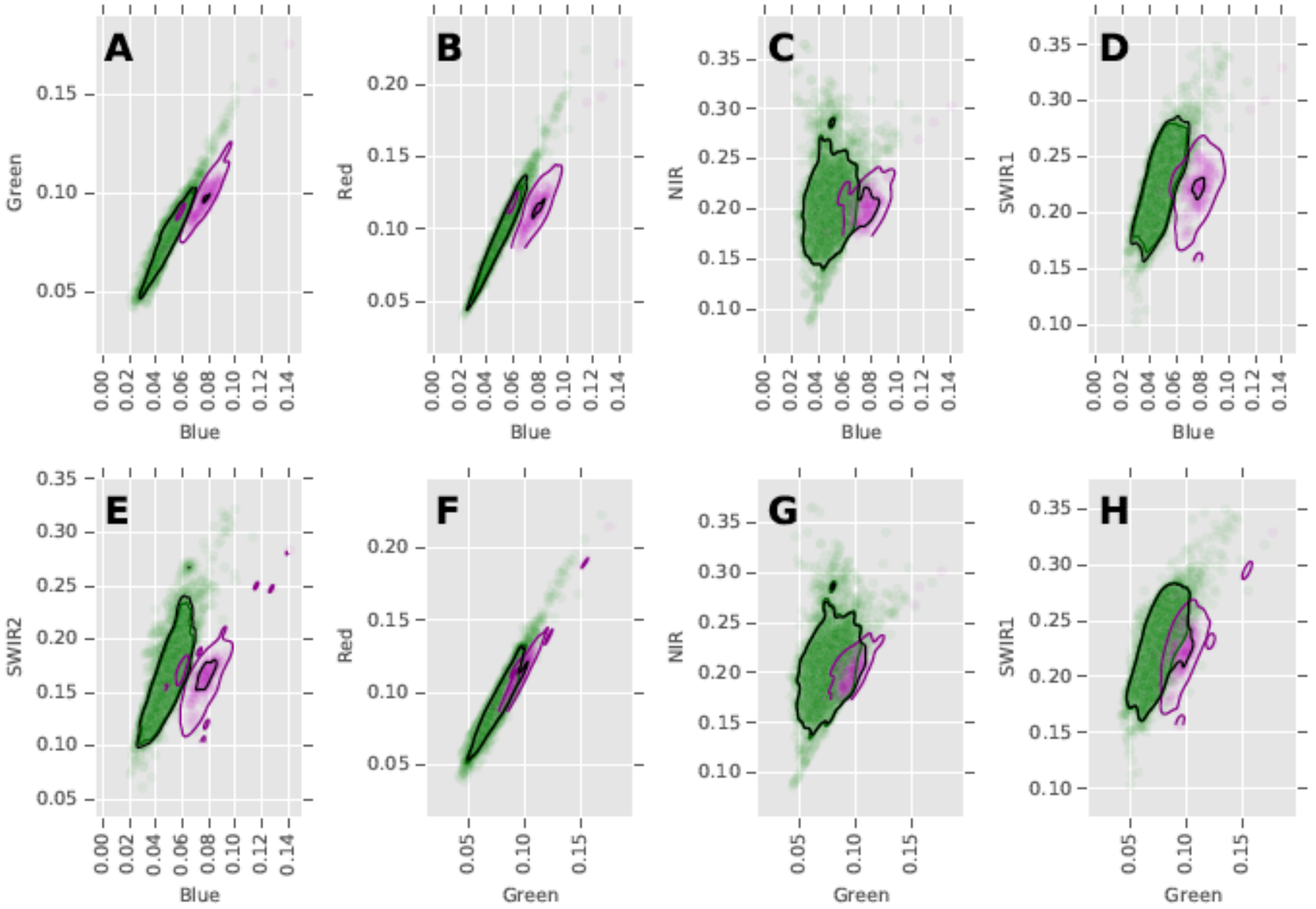
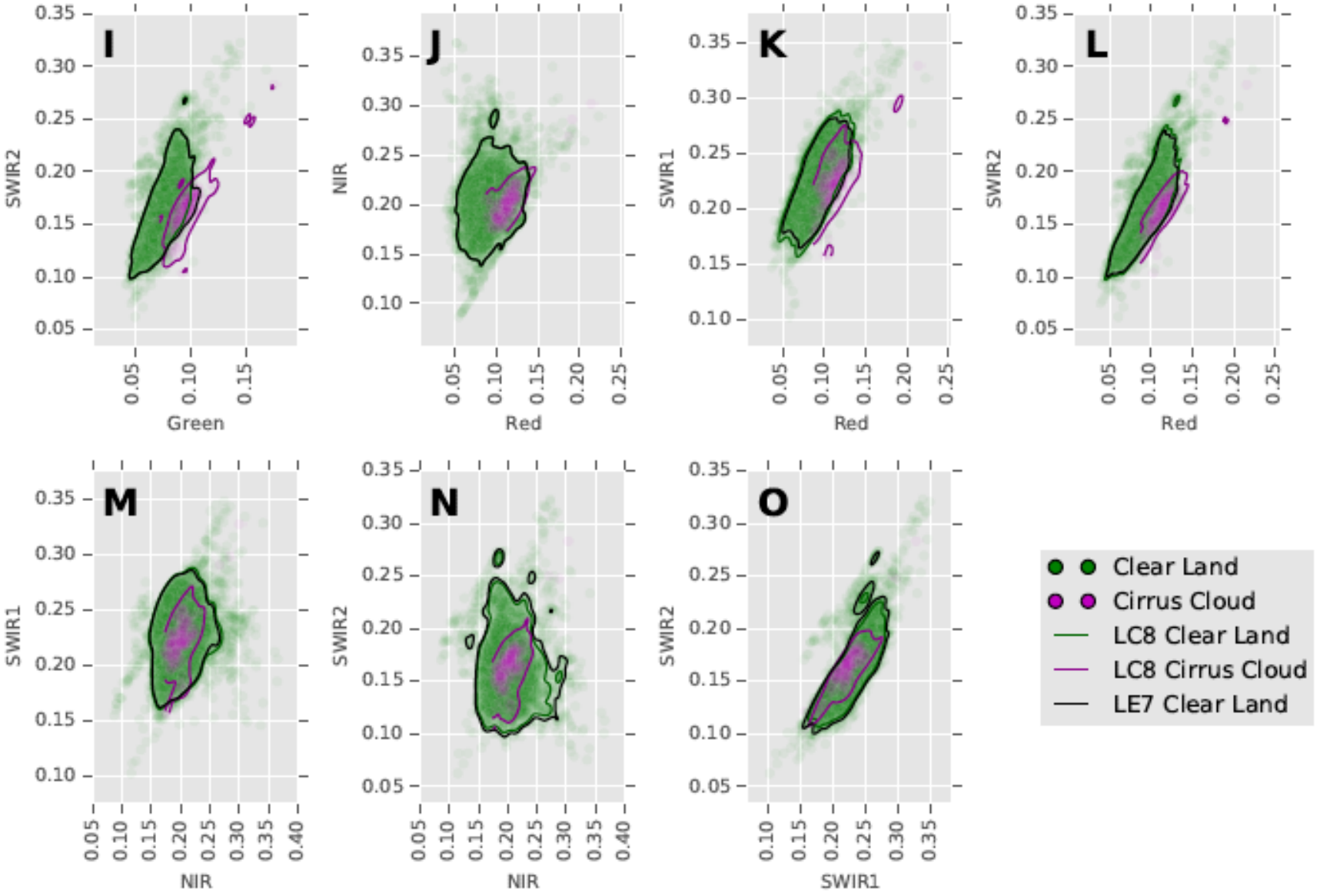


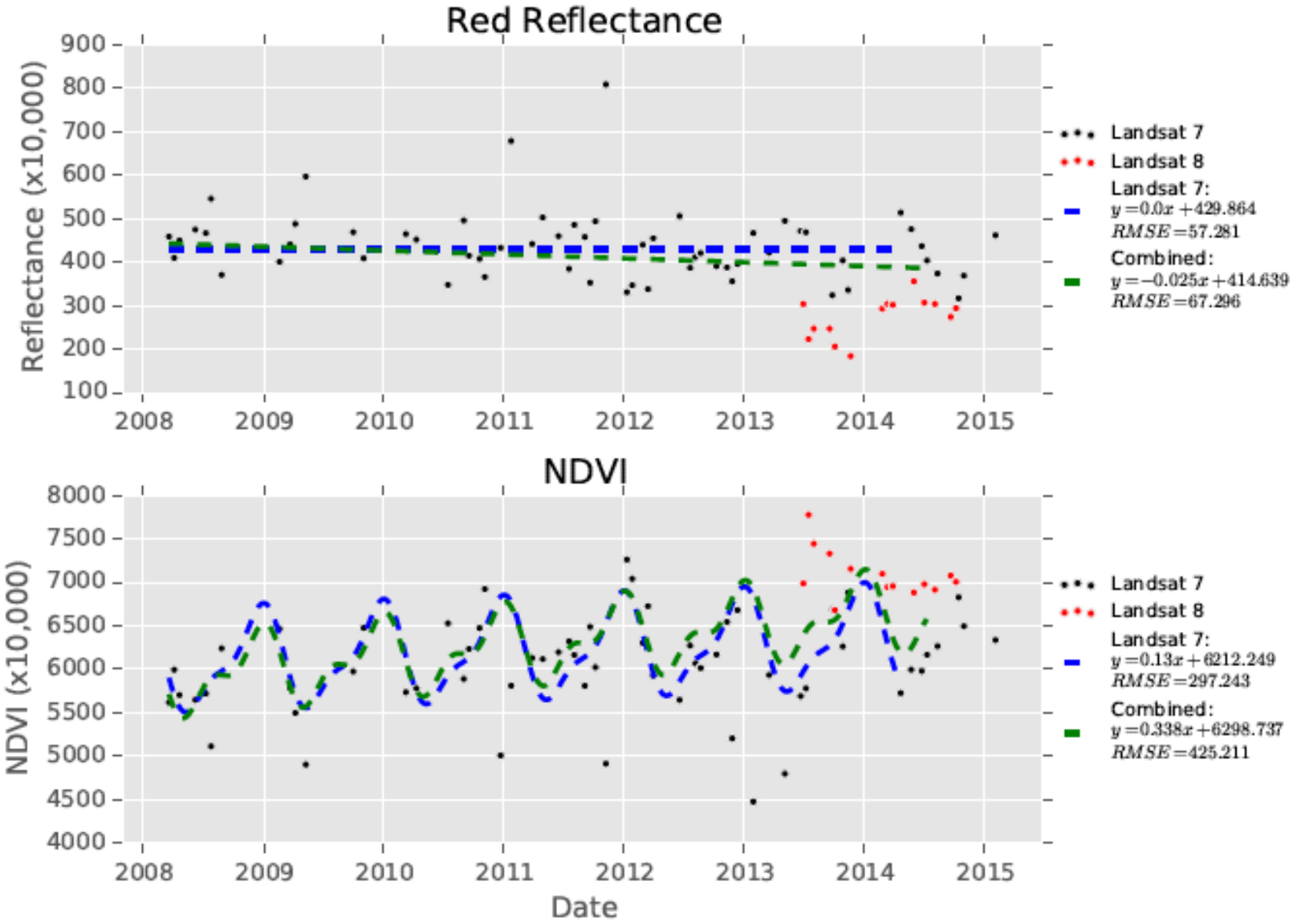
Effect of cirrus clouds on spectral reflectance



Effects of cirrus clouds on spectral reflectance

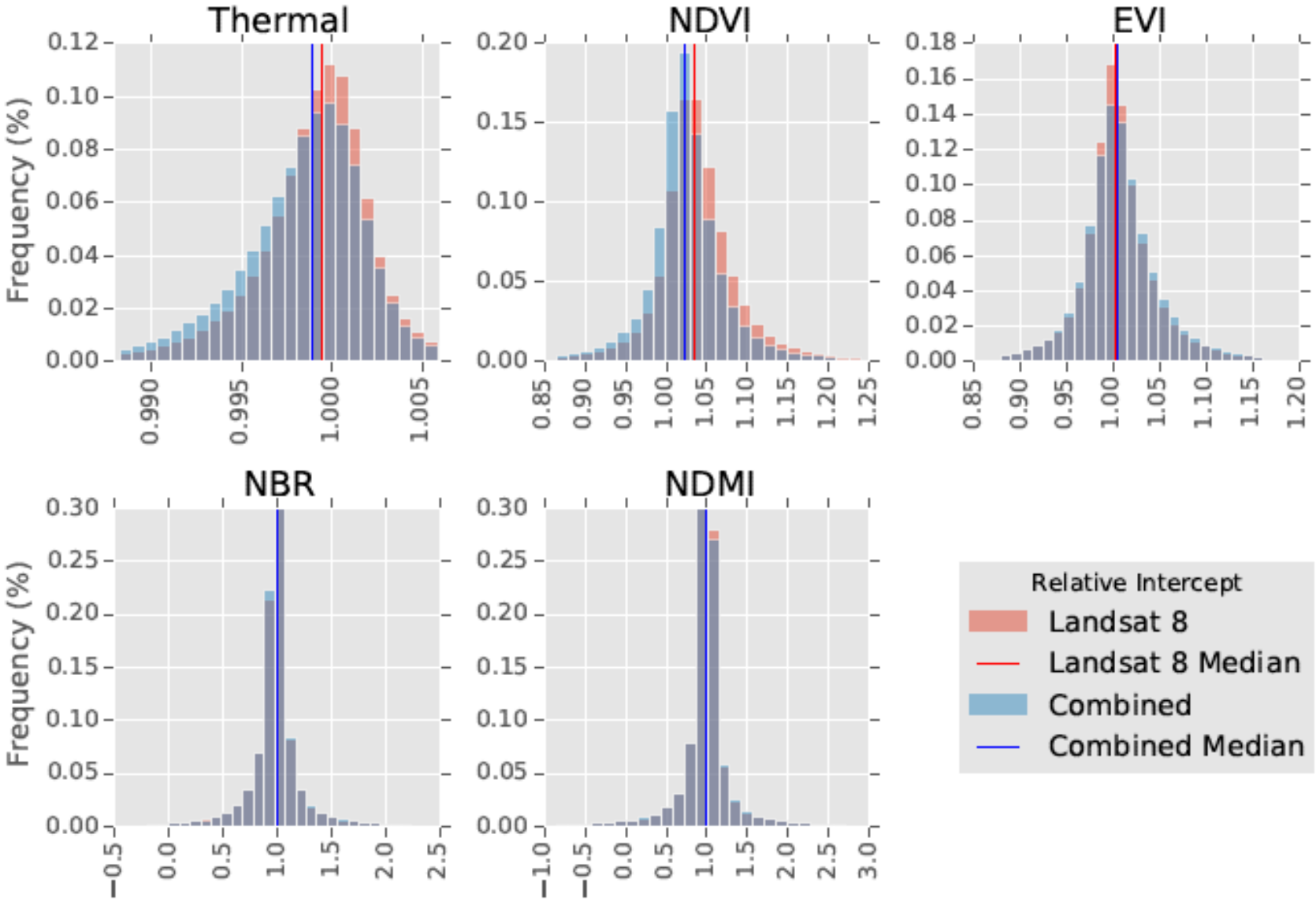


Time series and L7-L8 differences



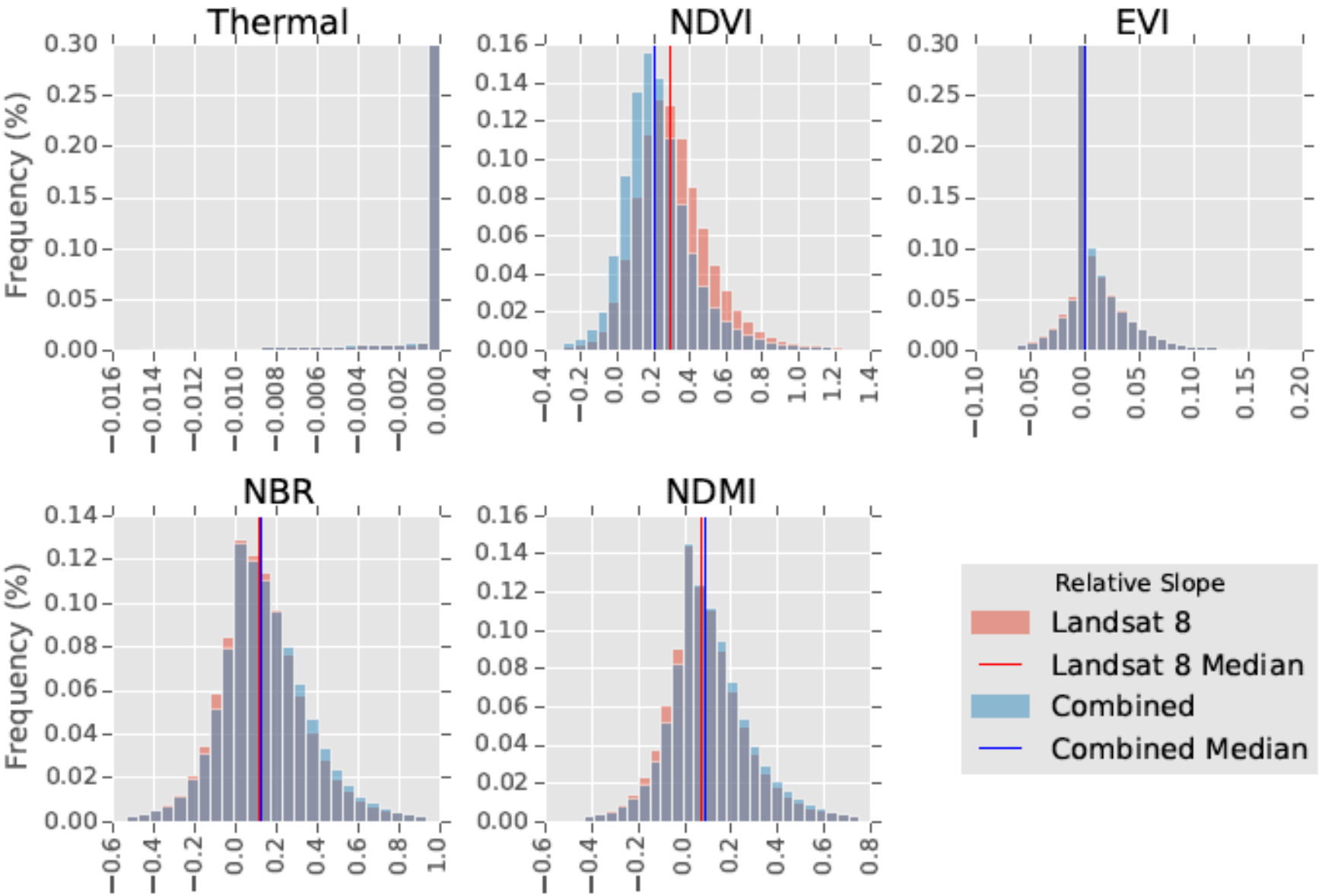
Changes in time series parameters due to combining L7 and L8 (intercepts)

Changes in time series parameters due to combining L7 and L8 (intercepts)



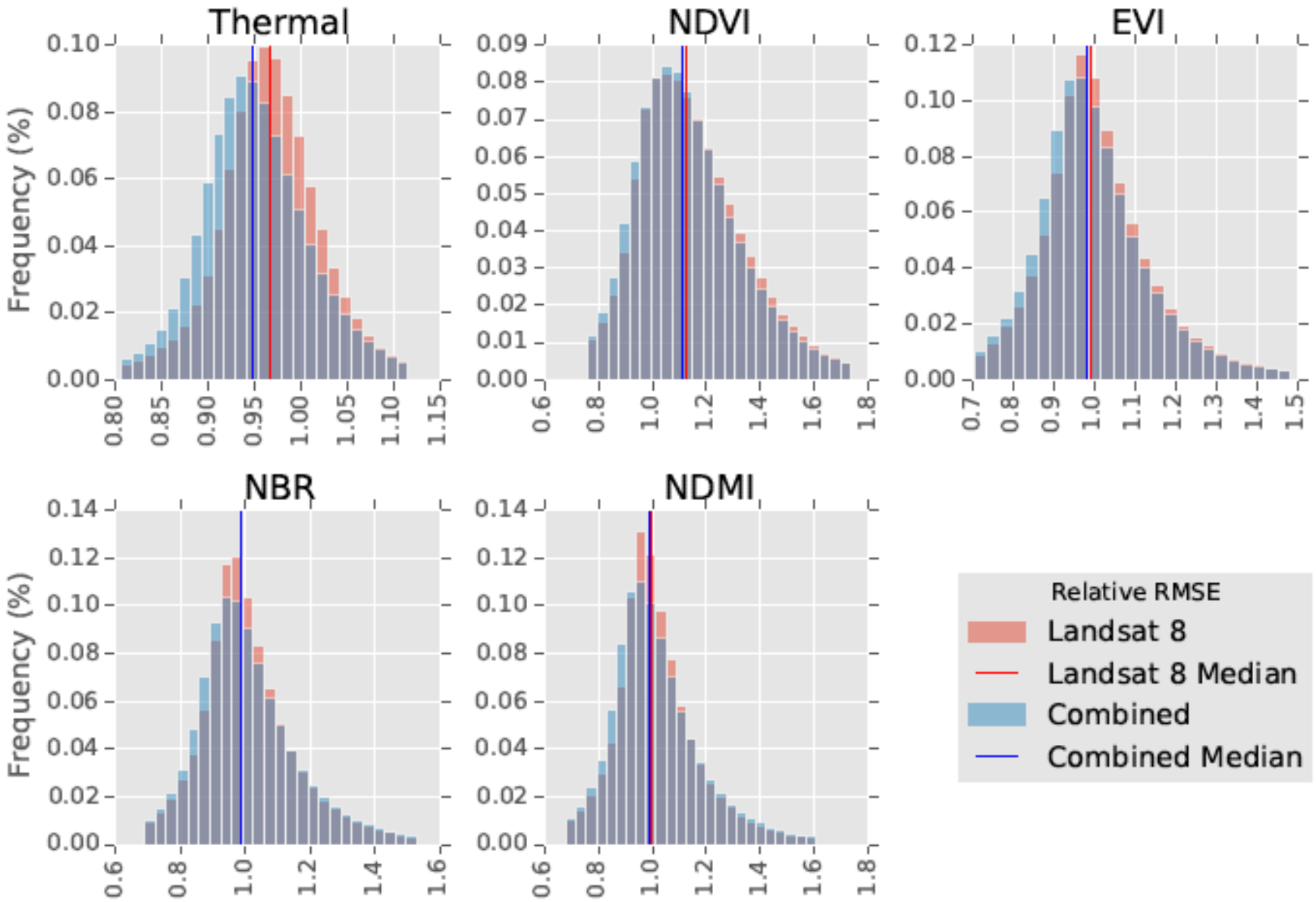
Changes in time series parameters due to combining L7 and L8 (relative slopes)

Changes in time series parameters due to combining L7 and L8 (relative slopes)

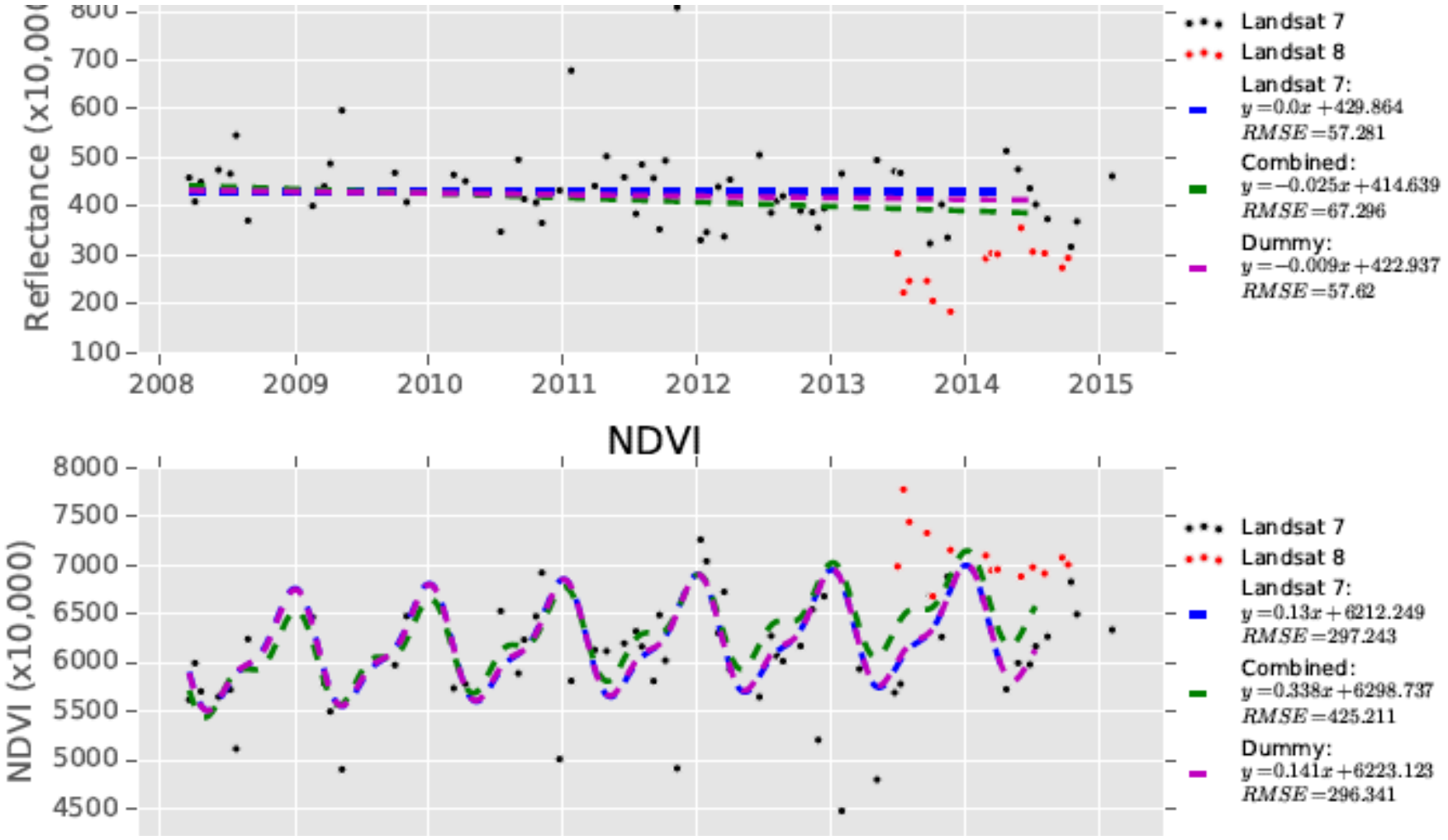


Changes in time series parameters due to combining L7 and L8 (relative RMSE)

Changes in time series parameters due to combining L7 and L8 (relative RMSE)



Time series model fits with and with out L8, and including a dummy variable for L8



Effect of cirrus clouds on time series models

- Short answer is minor changes in the intercepts and a bump in the RMSE of the models (they don’t fit as well)

What are we finding?

- Time series of Landsat have incredible advantages – more observations reduces the dependence on noisy single observations
- Time series reveal a complicated and rich history to places
- Time series allow characterization of condition and trends in ways not previously possible (phenology, growth, stress)
- Agricultural landscapes are by far the most dynamic and challenging (to the point of being diagnostic), and we need new ways to think about what constitutes change in these areas.
- The future looks really exciting …

Thoughts going forward

- While we are currently using primarily Landsat data, it will be exciting to include:
  - Sentinel 2
  - Sentinel 1
  - ALOS PALSAR
  - Chinese data???
  - Others???
- Initial attention has been on monitoring abrupt change, but with time we will focus on more subtle kinds of change

Implications for the Landsat Program

- Getting the calibration/atmospheric correction consistent across the whole TM/ETM+/OLI record is essential to effective use of the time domain!!!!!
- The Science Team needs to be providing crystal clear guidance on precisely how Landsat products (all the way from L1T and up) should be produced